NASA Tech Briefs

10/1

National Aeronautics and Space Administration

January/February
Volume 10 Number

Johnson Space Center: Beyond Mission Control

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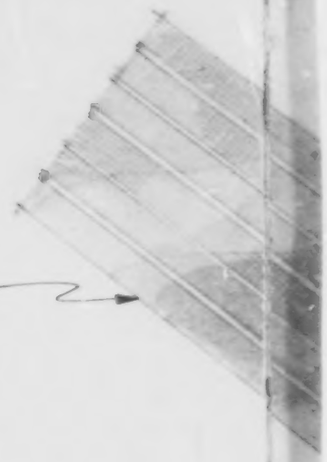
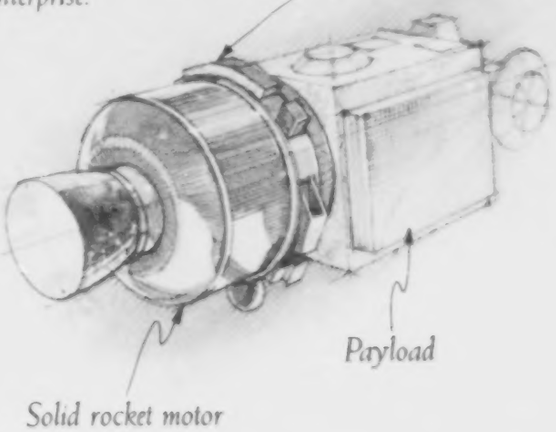
The next step: a space station that means business.

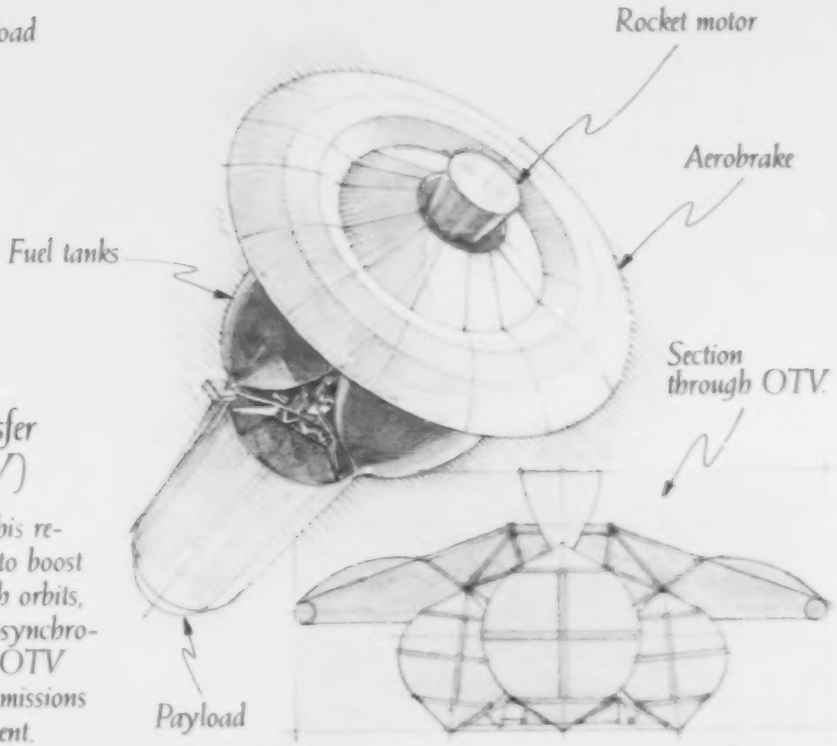
NASA has targeted the 1990s for deployment of a permanently manned space station. Martin Marietta is aiming to help NASA meet its date with advanced development of systems and spacecraft. As the permanently manned space station becomes a reality, it will open a new era of opportunity for government, science and private enterprise.





Transfer Orbit Stage (TOS)

The TOS will boost spacecraft and payloads from the Shuttle's low Earth orbit to geosynchronous transfer orbit.



Orbital Transfer Vehicle (OTV)

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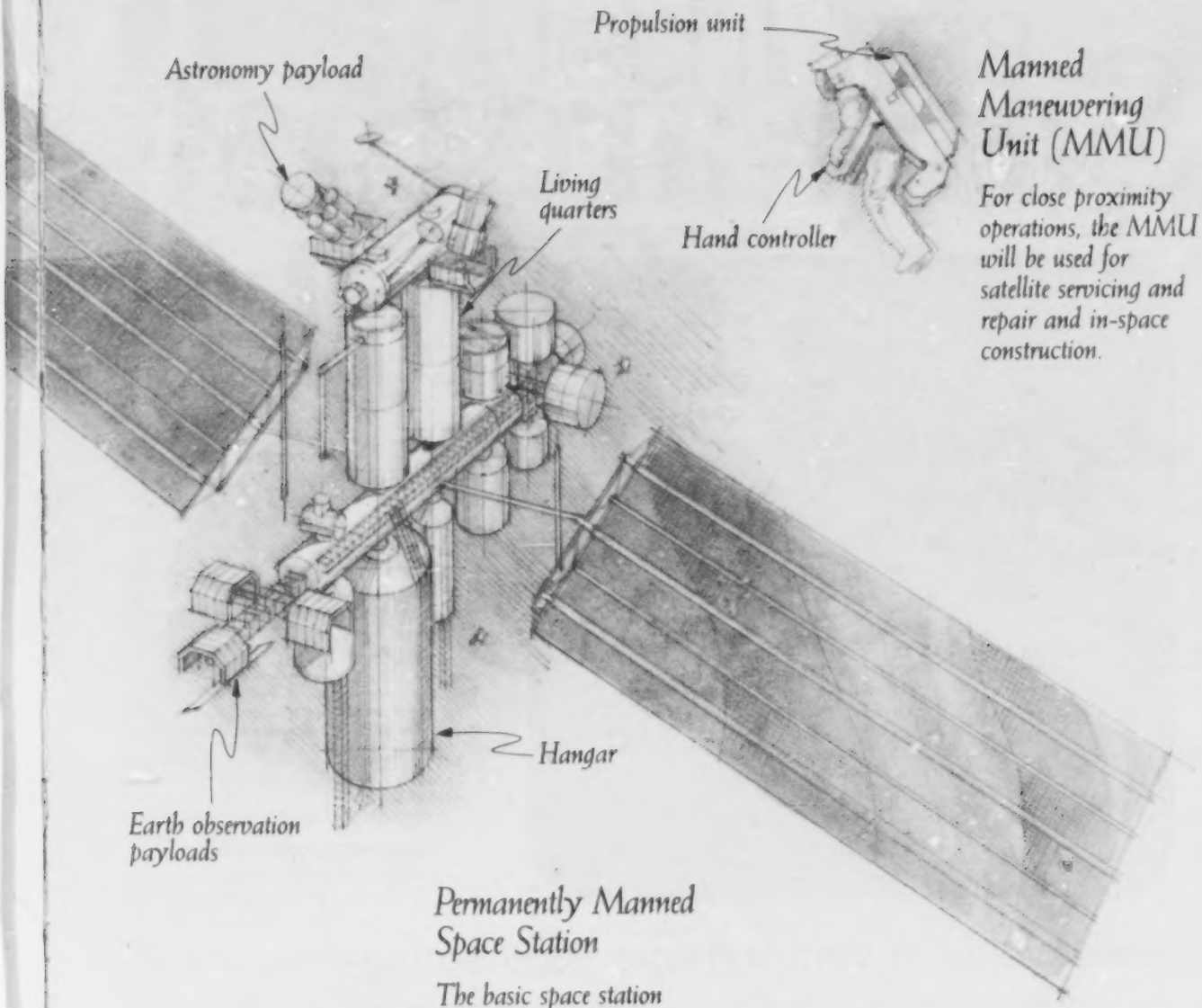

Manned Maneuvering Unit (MMU)

For close proximity operations, the MMU will be used for satellite servicing and repair and in-space construction.

Permanently Manned Space Station

The basic space station will be assembled from hardware and modules carried in the cargo bay of the Space Shuttle on successive flights. Subsequent flights will ferry crews and supplies, and deploy independently orbiting platforms.

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ON THE FRONT COVER:
Astronaut Bill Fisher trains for an extravehicular activity in the weightless environmental training facility (WET-F) at NASA's Johnson Space Center. The WET-F's neutral buoyancy simulates the conditions of weightlessness experienced by astronauts in space. For more on astronaut training, see "Johnson: NASA's Center Stage," which begins on page 8.

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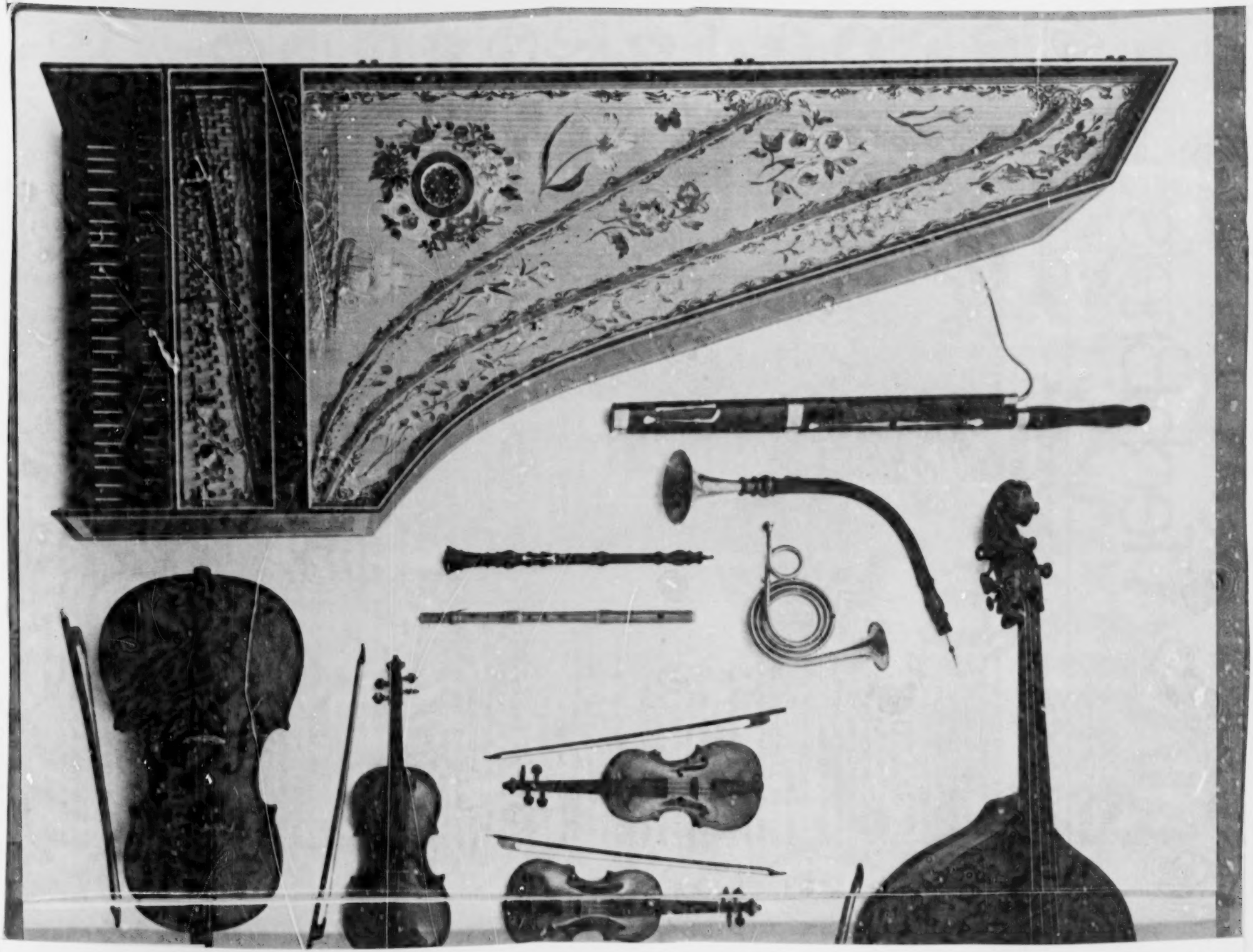

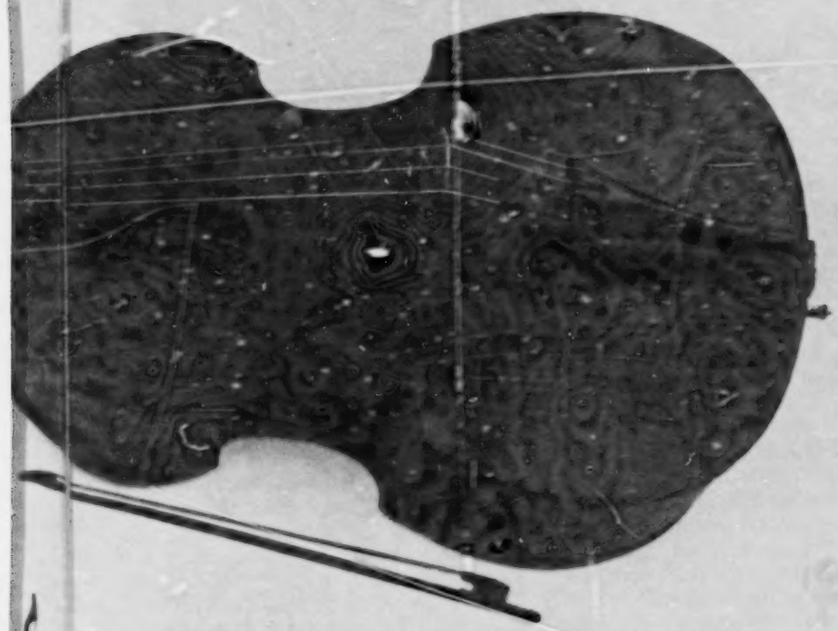

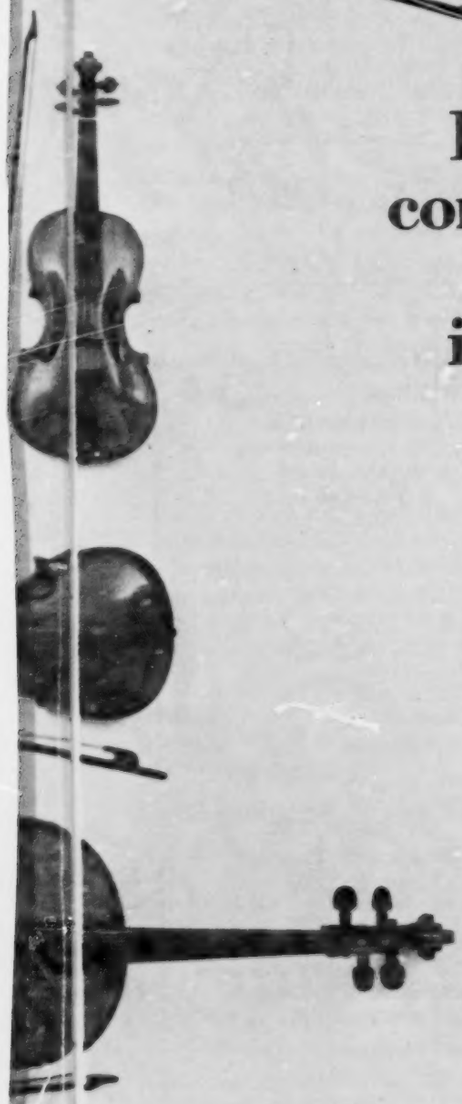

For years baroque music was composed without major change, until J.S. Bach put these instruments together in a way that set him apart.

All the baroque composers were faced with the same restrictions, the same notes, the same instruments, and the same musical forms. Yet today, we remember J.S. Bach above them all. Simply because he was able to arrange scores of music in a way no one had ever seen ... or heard before.

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Editorial Notebook

Picking Up the Pace

Beginning with this issue, *NASA Tech Briefs* becomes a bi-monthly magazine. You'll now be receiving six copies a year instead of the four you're used to receiving. There are several reasons for this, but the overriding one is the acceleration of technology transfer. As Robert A. Solo pointed out in testimony before the Senate Commerce Committee some years ago, "The value of information increases directly in proportion to the speed and breadth of its dissemination."

We've already increased the breadth of circulation . . . *NASA Tech Briefs* exceeds 100,000 circulation with this issue. Before we, the private publisher, joined NASA in this effort, the OMB-mandated circulation ceiling was 75,000. We have no circulation ceiling. Our goal is to ensure that *NTB* reaches every qualified reader who needs this information. We expect the increase in frequency will help address the other half of the equation that results in technology transfer.

The subject of technology transfer continues to surface in ever-widening circles. President Reagan recently hosted a White House reception for participants in the National Initiative on Technology and the Disabled. The Initiative was created under the auspices of the Department of Health and Human Services to ensure that new and emerging medical technologies, many of which are spinoffs of NASA R&D, are made available to the people who need them. To this end, the Initiative established TECHNET, a national information network for disabled citizens, and TECHTEAM, a nationwide network of local technological professionals who are applying their skills, knowledge and talents to the problems of the disabled.

A different sort of technology transfer is taking place at NASA's Johnson Space Center, the subject of this issue's editorial feature. Agreements between Johnson and private companies provide for technical cooperation in a number of commercial space ventures, among them the Industrial Space Facility, which will be compatible with Space Station, and a privately-financed upper stage booster.

People transfer technology, and among those who do are (from left): Bill Chmylak, Technology Utilization Officer at Johnson Space Center; Isaac T. Gillam IV, NASA's Assistant Administrator for Commerical Programs; Bill Schnirring, NASA Tech Briefs Publisher; Gerald Griffin, Director of Johnson Space Center; Marvin Matthews, Patent Counsel at Johnson Space Center; and Len Ault, Deputy Director of NASA's Technology Utilization Division.

For more on Johnson, turn the page, but before you do, best wishes for a happy new year from all of us at *NASA Tech Briefs*. We'll be working hard to make your publication the best it can be, and we appreciate all the feedback you've been giving us. Don't stop. □

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With the increasing importance of personal computers in government, and with the corresponding need for greater data storage capacity, 3M has added to its line of data cartridge products one with a capacity of more than 20 megabytes.

Called *3M* Brand DC 2000 Data Cartridge, this new development will be made available through contractors who are designing and producing personal computer drives.

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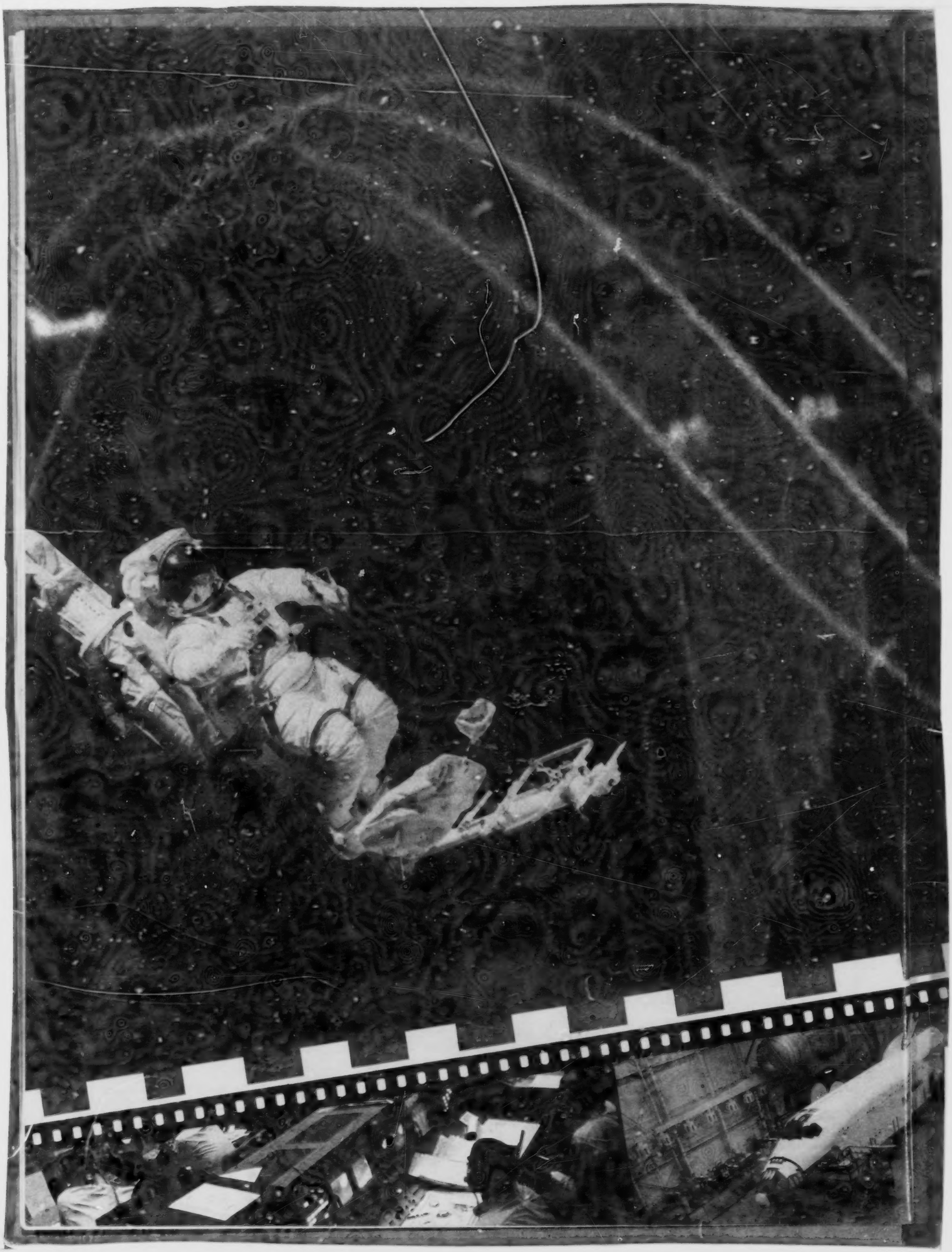


Johnson:
NASA's Center Stage

If any one of NASA's nine field centers could be said to characterize the essence of the agency, that center would most likely be Johnson Space Center, at least as far as the public is concerned. And if one were to ask why, the answer might be simply: "astronauts." Either that or "mission control." Certainly it's the drama of humans venturing into space which has drawn public attention to the center, and much of the world has watched this drama unfold via the wide-angle lenses mounted in Johnson's building 30, the mission control center.

Johnson Space Center came into being just as America's manned spaceflight program got off the ground. Less than a month after Alan B. Shepard's historic suborbital flight aboard the Mercury capsule "Freedom 7," President John F. Kennedy proposed that the nation undertake the challenge of a manned lunar landing and safe return to earth, and accomplish it before the end of the 1960s.

The lunar commitment meant a number of things to NASA, among them the need for expanded operations and facilities. In September 1961, NASA administrator James E. Webb announced that a new Manned Spacecraft Center would be built on a 1620-acre prairie site, southeast of Houston, Texas. The new center would be the permanent home of the Space Task Group, the team of scientists, administrators and clerical personnel based at Langley Research Center in Hampton, Va., that had planned Project Mercury. The Manned Space- ►

***The Emblem of an Era:** The tracking screen at mission control is the backdrop for astronaut Bruce McCandless (left), who's attached to the shuttle remote manipulator system's mobile foot restraint, and the orbiter Columbia. Below (left to right): mission control operations during Apollo 10, shuttle mock-ups at Johnson Space Center, Skylab, and astronaut Bill Fisher underwater in Johnson's weightless environmental training facility.*

Johnson

craft Center, which was renamed the Lyndon B. Johnson Space Center in 1973, would be NASA's lead center for the design and development of manned spacecraft, the selection and training of astronauts, and the operational control of manned spaceflights.

Construction at the Houston site began in April 1962. Two years later, the first of the center's major buildings were ready for occupation, and in June 1965, those who monitored the course of the second manned Gemini mission did so from the vantage point of mission control.

Throughout the 1960s, as the drama, suspense and spectacle of the Apollo program unfolded, the Houston center played host to the hundreds of newspaper and television reporters who covered the space beat. Because reporters were not actually allowed inside mission control during the course of spaceflights, television cameras and microphones were mounted inside the room to give reporters and the public access to history in the making. "One small step for man, one giant step for mankind" may be the most memorable words from the lunar surface, but they weren't the first. That distinction, and those words, "Houston, Tranquility Base here, the Eagle has landed," were directed to mission control, the heart of the Manned Spacecraft Center.

Heart and Soul

If mission control is at the heart of Johnson Space Center, then the astronauts are close to its soul. Everyone from the "original 7" Mercury astronauts to the burgeoning corps of shuttle commanders, pilots, mission and payload specialists has spent a good deal of time in Houston, whether going through the selection process or training for missions.

Astronaut training is conducted under the auspices of Johnson's space operations directorate. Full-scale mock-ups of the shuttle itself are located in building 9A, and a variety of systems and mission simulators, complete with windows on which actual space scenes are projected, are in building 5. Here the shuttle astronauts familiarize themselves with orbiter hardware and software, much as those who came before them did with Gemini, Apollo and Skylab mock-ups and simulators.

The focus of the training program is routine—with a capital "R." Astronauts perform the tasks necessary to successful spaceflight again and again and again. Every imaginable "what if . . . ?" is thrown into play, so that by the time a mission is ready for launch, a bare minimum of the unexpected is left to expect.

Time-lines are established as the crew becomes more and more proficient at performing its tasks, and these are used in mission planning—determining its duration and scheduling the sequence of on-orbit activities. A full dress rehearsal, involving both shuttle crew and simulators, and ground crew, tracking stations and mission control precedes every spaceflight.

Flights aboard NASA's KC-135 aircraft serve to familiarize astronauts with the experience of weightlessness. The KC-135's pilot flies a parabolic curve flight profile, exposing astronauts to a brief period of zero-gravity, during which they become accustomed to weightlessness and practice tasks such as spacesuit donning.

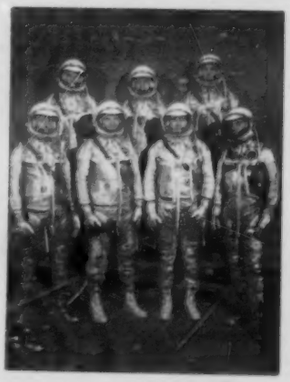
Those astronauts who will be performing extravehicular activities (EVAs) receive additional training in Johnson's weightless environment training facility—the WET-F. Astronauts don their bulky extravehicular mobility and manned maneuvering units before being lowered into a 25-foot deep "swimming pool." A full-scale mock-up of the shuttle's cargo bay rests at the bottom of the neutral buoyancy WET-F. There the astronauts, monitored for safety by trained scuba divers, learn to perform the maneuvers and tasks, such as tending experiments and deploying satellites, that they'll repeat in space during the actual EVA.

Behind the Scenes

While much of the public's attention focuses on astronauts and shuttle missions, much of the activity at Johnson Space Center focuses on the research and engineering which support continued operation and improved performance of the shuttle program. Johnson's research and engineering directorate is divided into two major organizations: space and life sciences, and engineering.

Space and life sciences includes a space bio-medical research institute, which conducts research into the impact of space travel on human physiology. Space adaptation syndrome, otherwise known as space motion sickness, is one area where researchers are concentrating. (Roughly ►

On Becoming an Astronaut



The "original 7" Mercury astronauts.

Astronauts are made, not born, so becoming one in the '80s is as much a matter of the right credentials as the "right stuff." To be eligible to apply to the program, would-be astronauts must meet minimum educational and physical requirements. These differ somewhat, depending on whether one wishes to apply as a pilot astronaut or as a mission specialist. (Pilot astronauts fly the shuttle, while mission specialists manage shuttle systems and operate the payloads and experiments during flight.) In either case, applicants must hold a bachelor's degree in engineering, biological or physical sciences, or mathematics.

An advanced degree and/or equivalent professional experience are desirable for pilot astronauts, and required for mission specialists. Further, pilot applicants must have logged at least 1,000 pilot-in-command hours in jet aircraft, and both groups must be able to pass stringent NASA space flight physicals, which place special emphasis on visual acuity, hearing, and blood pressure. Finally, pilot applicants must be between 64 and 76 inches tall, while mission specialists must be between 60 and 70 inches.

Through its astronaut selection office at Johnson Space Center, NASA accepts applications from civilians on a continuing basis (military applicants apply through their branch of the armed services). After reviewing the applications, NASA develops a selection roster, and invites the highest-ranking applicants to Johnson for interviews and medical evaluations. Based on upcoming mission requirements and the astronaut corps' rate of attrition, NASA selects a number of astronaut candidates annually.

The most recent group of 13 astronaut candidates was selected last June from a roster of 33 civilian applicants and 133 military nominees. Of these, 59 were interviewed at Johnson and, finally, five civilian and eight military candidates were selected. They reported to Johnson late last summer to begin a year-long period of training and evaluation, at the end of which they'll become full-fledged astronauts, ready for assignment to a shuttle crew.

The new candidates join NASA's current corps of 90 flight-status astronauts. In all, 157 persons have been named astronauts since the program began in 1959 with the selection of the "original 7," the founders of that illustrious order which turns qualified earthlings into space travelers. □

An astronaut information and application packet may be obtained by writing to: Johnson Space Center, Astronaut Selection Office, Attn: AHX, Houston, TX 77058.

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In 1492, a Genoese navigator and an intrepid crew braved uncharted waters in search of a west passage to India. In the process, they discovered the vast resources of two continents. And they opened up a new base for exploration, progress, and the hopes of mankind.

In 1992, coincident with the 500th anniversary of Columbus's voyage, we plan to set sail for another New World. That year, or shortly thereafter, the United States and the world will begin benefiting from the first manned Space Station. The Station will be more than another giant step for mankind. It will be our stepping stone to living in new realms, and it will result in thousands of discoveries that will benefit earth.

This New World, free from gravity and atmospheric impurity, will provide that ideal environment for experimentation and production that is impossible on earth. Simultaneously we will have a permanent station for scanning the earth and the heavens—an unparalleled vantage point for predicting weather, aiding agriculture, and understanding the universe.

Of course, like Columbus, we cannot foresee all the benefits ahead. But we do know that we will have a new arena in which to conquer disease, transform the materials of earth, and generate precious energy. The resulting knowledge from countless discoveries will come down to earth for our well-being.

But, unlike Columbus, our craft will be in constant contact with the Old World. Harris Aerospace, as a member of the Rockwell, Grumman and Sperry team, is responsible for the Space Station's communications and tracking system. We are totally committed to this great endeavor, and we bring to the challenge the capabilities and experience necessary for success.

Harris has had 27 years of successful involvement with the kind of space communications and tracking required for the manned Space Station. Our space experience includes programs from Telstar to the Tracking and Data Relay Satellite as well as the manned programs of Apollo, Lunar Module, and Space Shuttle. We are also a leader in the architecture and design of large communication networks.

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For in 1992, we, too, will be very much like Columbus: carrying the sum of our knowledge into the unknown. And, like him, we, too, shall return with the bountiful gifts of a New World.

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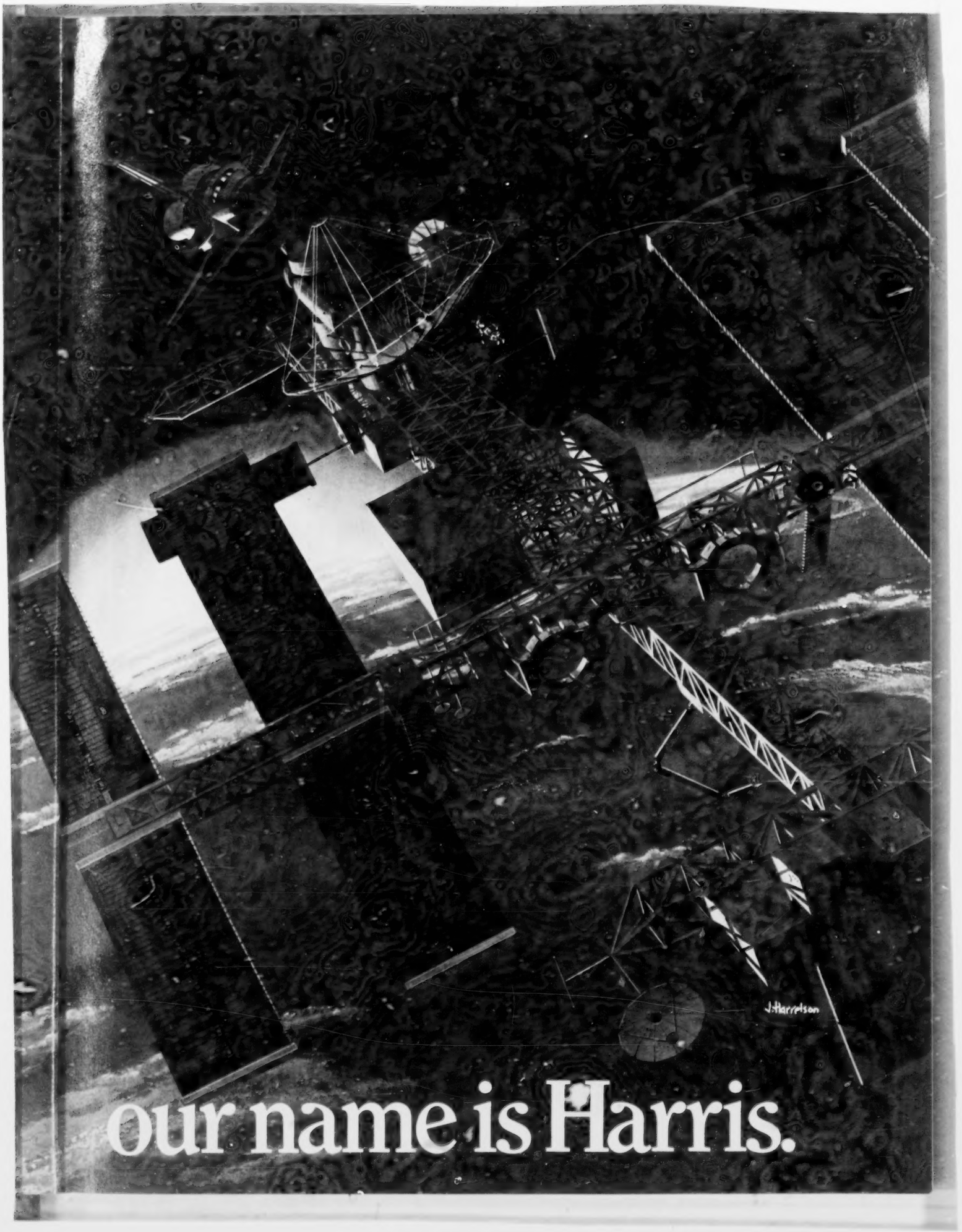


our name is Harris.

Johnson

50% of the people who fly in space experience some symptoms of space motion sickness during the first three to four days of spaceflight.) At present, there appears to be no clear correlation between space motion sickness and its earthly counterpart. Astronauts who experience motion sickness during ground tests are often free of its effects while in space, and those who experience space motion sickness are often immune to the effects of the ground tests, some of which employ a rotating chair. Johnson bio-medical researchers are working on various techniques, which range from drugs to bio-feedback, to control the effects of space motion sickness while they continue to search for its cause.

Other researchers at Johnson's space bio-medical institute focus on calcium loss during prolonged spaceflight. This work is a carryover from the mid-1970s, when Skylab astronauts who remained in space for 84 days experienced a 10% loss of bone calcium. NASA's plans for a permanently manned space station make this research increasingly relevant, since space station crews will be likely to stay in space for months at a time.

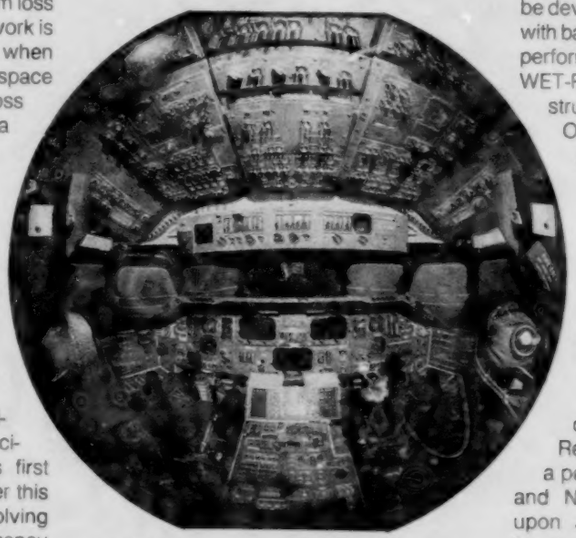
In addition to the space bio-medical research institute, the medical sciences and life science projects divisions also come under the auspices of the space and life sciences organization. Medical sciences does the operational medicine for shuttle crews, while life sciences is preparing for Johnson's first Spacelab mission, which will fly later this year. Spacelab, a joint program involving NASA and the European Space Agency (ESA), provides versatile laboratory facilities that accommodate a variety of scientific experiments, many of which are extensions of Skylab research. While previous Spacelab missions have focused on scientific investigations into solar, atmospheric and plasma physics, and materials science in a microgravity environment, the Johnson-managed Spacelab 4 will be largely a life sciences mission.

Three other programs complete the space and life sciences organization. The solar system exploration division is a carryover from the Apollo era, and researchers there continue to analyze lunar materials and meteorites, in addition to space debris.

The man-systems division explores man-machine relationships and how these relationships change in the space environment. Man-systems personnel develop meal plans and procedures for spaceflights, and determine what sorts of food preparation techniques are best-suited to the limited capabilities of the shuttle galley. They also develop other habitability-related equipment, such as zero-gravity showers and sleeping restraints. This division, incidentally, also maintains the crew training equipment, such as the mock-ups and the WET-F, and man-systems personnel use them in developing the training procedures which are later taught to astronauts. Finally, an artificial intelligence and information sciences office completes the space and life sciences directorate.

Working Together

Johnson's space and life sciences programs are closely allied with its space operations directorate, especially where crew training and crew systems are concerned. Similarly, Johnson's engineering directorate supports space operations in a variety of ways.



A "fisheye" view of the space shuttle procedures simulator.

The engineering directorate consists of several divisions, each of which tends to focus on a specific engineering discipline or spaceflight system. The crew systems division, for example, develops life support systems, environmental controls, spacesuits and the manned maneuvering unit (MMU), a powered backpack which propels astronauts during EVAs. The propulsion and power division works with devices such as fuel cells, batteries and auxiliary power units which fly onboard the shuttle. The cargo integration office is concerned with systems which secure payloads in the shuttle cargo bay, and the tracking and communications division provides the systems needed to communicate with the earth and with other spacecraft.

The structures and mechanics division focuses on the materials and mechanical systems that, together, form a spacecraft, while the avionics system division manages all the hardware and software that combine to create the shuttle's data management avionics system. The simulation and avionics integration division is involved in some crew training, and in evaluating the performance of shuttle systems, such as the remote manipulator arm and shuttle avionics—how the orbiter flies.

Essentially, Johnson's engineering organization is devoted to maintaining cost-effective and routine operational status for the space shuttle. Its tasks range from fixing the brakes on the orbiter to handling problems which arise during the course of actual shuttle flights. Often, new systems and/or procedures must be developed literally overnight, when an on-orbit malfunction or failure occurs. An example of this sort of contingency action might be a satellite that fails to activate following deployment from the shuttle. A device for triggering the satellite's power system will be developed at Houston. Then it is tested with back-up hardware, and simulations are performed in both the mock-ups and the WET-F to develop procedures for constructing the device and for using it. Once established, these procedures are transmitted to the shuttle crew for use in the actual attempt to activate the satellite.

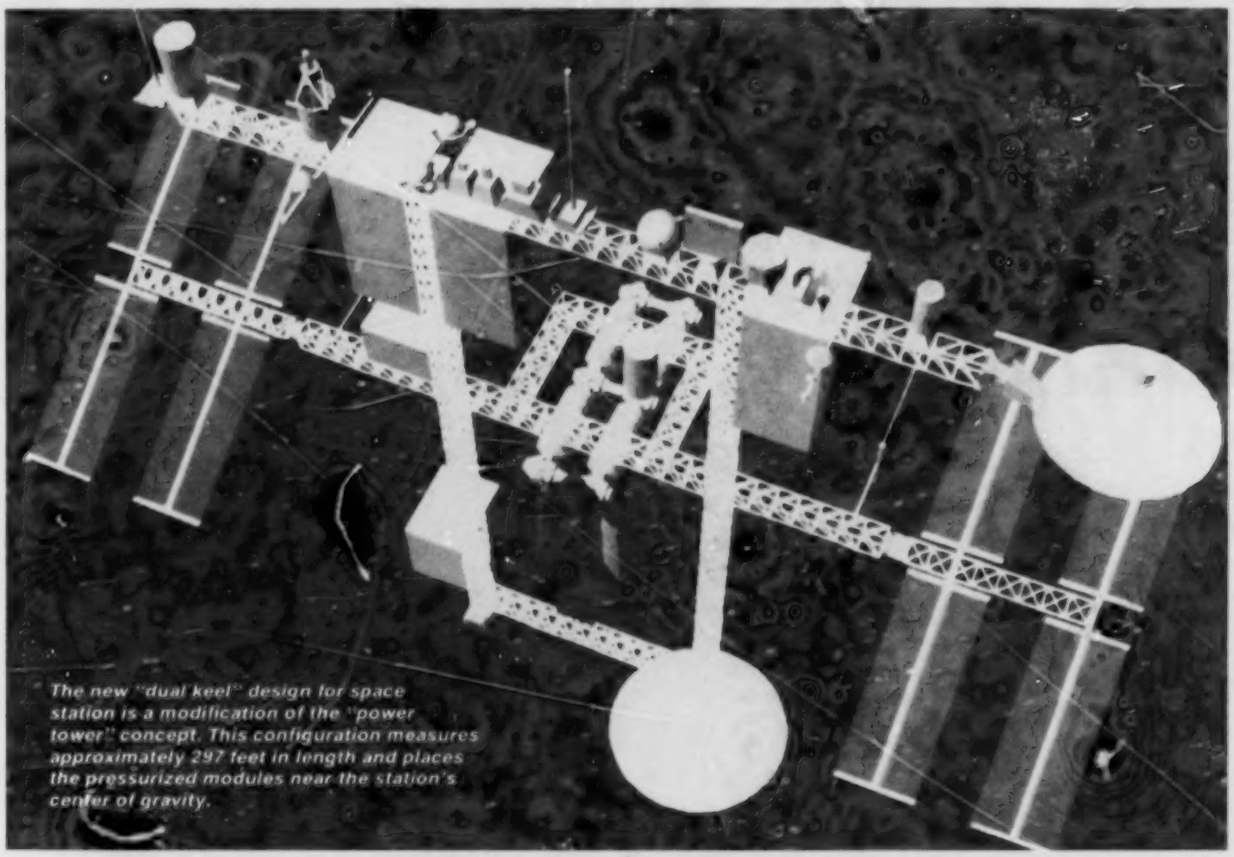
Gearing Up

Now that the space shuttle has achieved routine operational capability, the focus of activity at Johnson Space Center has begun to shift. In his 1984 State of the Union Address, President Reagan called upon NASA to develop a permanently manned space station, and NASA, shortly thereafter, called upon Johnson to act as lead center for the new project. NASA-sponsored industry studies yielded a number of design alternatives during 1984-85. These are currently being considered at Johnson, which is responsible for the design and development of space station's structural framework. A definitive design will be established during 1986-1987.

Johnson engineers will be designing and developing space station's thermal and attitude control systems, and its communications and data management systems. The integration and installation of these and other systems into space station's overall structure will be managed by Johnson as well.

Johnson's space station program office is helping to coordinate the work of the other NASA field centers, specifically Goddard, Marshall and Lewis, which are handling three of the four work packages which comprise space station.

Johnson has established a space station systems engineering office to initiate design and development work on space station systems. With a tentative launch date of 1992—the 500th anniversary of the voyage of Columbus—it's to be expected



The new "dual keel" design for space station is a modification of the "power tower" concept. This configuration measures approximately 297 feet in length and places the pressurized modules near the station's center of gravity.

Johnson

that this inaugural engineering work will begin spilling over into the other engineering offices. Yet, since an operational space shuttle program is germane to the concept of space station, sustaining work in this area will continue and, no doubt, modifications designed to accommodate the particular needs of space station will be developed and incorporated.

As space station moves from the drawing board toward the launchpad, it opens up a new and expansive realm of possibilities for continuing the human venture into space. Johnson's advanced programs office is studying the feasibility of a number of projects which use space station as a point of departure, among them a lunar base and a manned expedition to Mars. While plans to go ahead with these programs have not yet been made, the fact that they exist as feasibilities should be exciting to everyone who looks forward to the continued exploration of space.

Coming of Age

Now that the frenzy of media activity which surrounded the Apollo program has abated, it's often difficult to get information on exactly what's happening with the American space program. The routine launches and landings of the shuttle probably help to create the impression that space just isn't as exciting a topic as it used to be. Behind this somewhat superficial perception of the current American space program is a fundamental change in the way NASA manages its manned spaceflight programs. Joseph P. Loftus, assistant director in charge of plans at Johnson Space Center, characterizes the change as follows:

"If you hark back to the '60s, we did things all under the banner of a mission. So you had Apollo, whose mission was to land on the moon, and Viking, a mission to Mars, and so forth. What's going on now is we are passing through a major watershed. We are uncoupling facilities and capability from the mission. The shuttle doesn't have a mission; it has a capability and it flies missions. The space station doesn't have a mission; it is a facility which will accommodate many, many mission objectives. I think that makes for a very significant change in the character of activities in an organization, when you go from very explicit mission objectives, with everything in effect custom-designed, to this different world of capabilities.

"What we're trying to put in place is a space operations system, of which the shuttle is the part that gives us access to low-earth orbit, return from orbit, recovery, retrieval, sorties, and then the space station is an extension of that capability. It gives us permanency, a locus where we can have a depot, so we no longer have to take things back and forth. We can accumulate things on-orbit. That's a very large increase in the efficiency of activity. And then, of course, once you get that, there is a natural corrolary which says you can begin to space-base activities, so that you can assemble things on orbit, and you can have your higher energy transportation systems based in space, rather than based on earth. Once you have those elements in place, you have a basic operations infrastructure, with which you can do whatever it is that seems appropriate or attractive."

As NASA moves into the '90s, its facilities and capabilites will continue to expand and mature. At the same time, new facilities and capabilities will emerge—witness the recent West German Spacelab mission. Payload monitoring and management was conducted at the West German Space Operations Center in Oberpfaffenhofen, West Germany. Space station will help to expand this user community by offering a permanent presence in space for private industry and research. Further, agreements between NASA and the European, Canadian and Japanese space agencies will give space station an international aspect.

Even in the midst of this diversification, Johnson Space Center will retain a starring role in the burgeoning space enterprise. As lead center for space station, Johnson will focus both the domestic and international efforts which support the program. And when space station becomes operational in the early 1990s, the world will see what there is to see through those same wide-angle lenses at mission control. □

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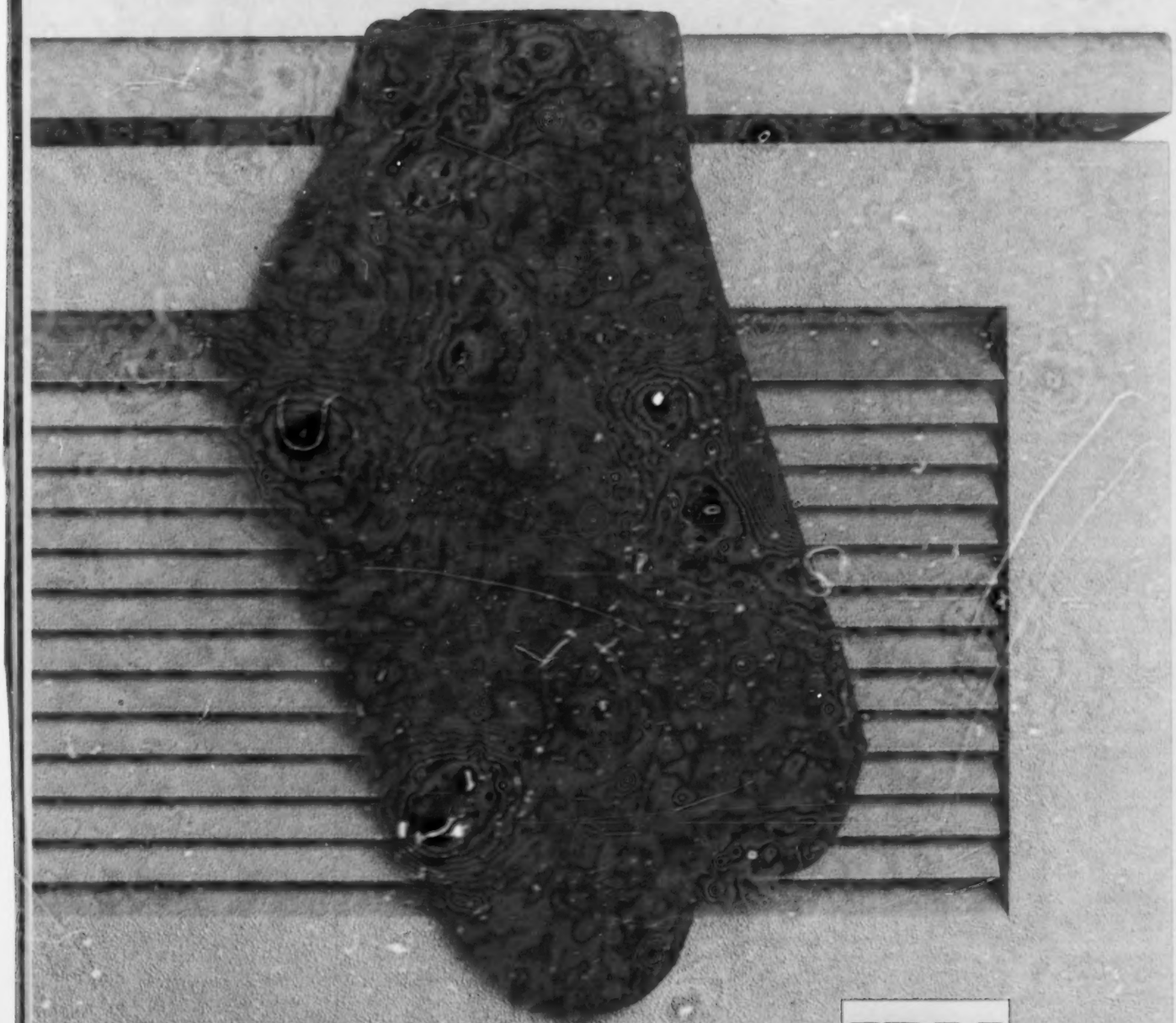

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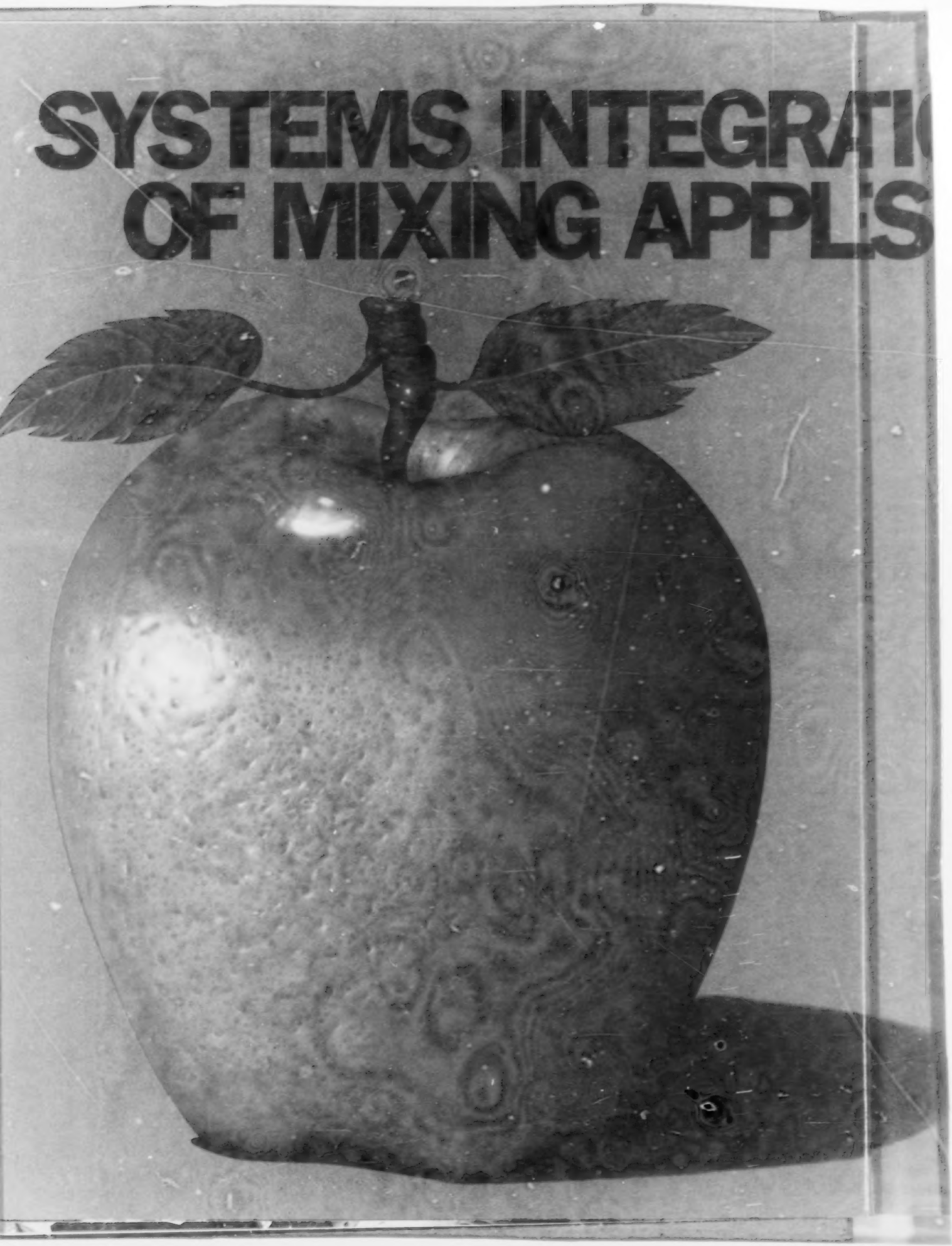

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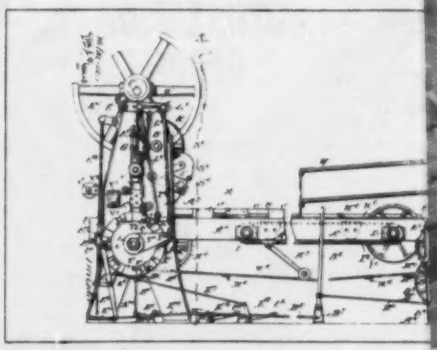

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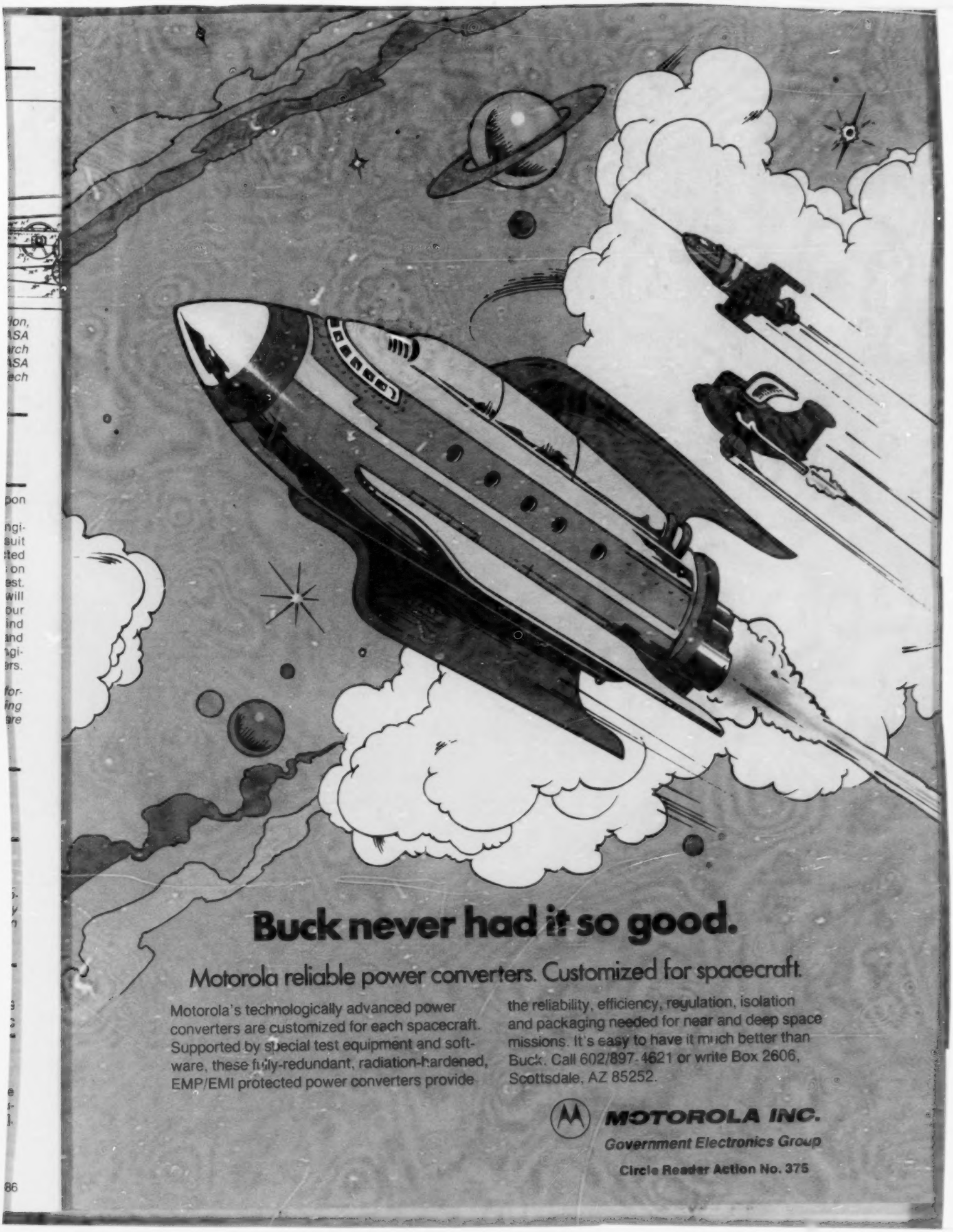

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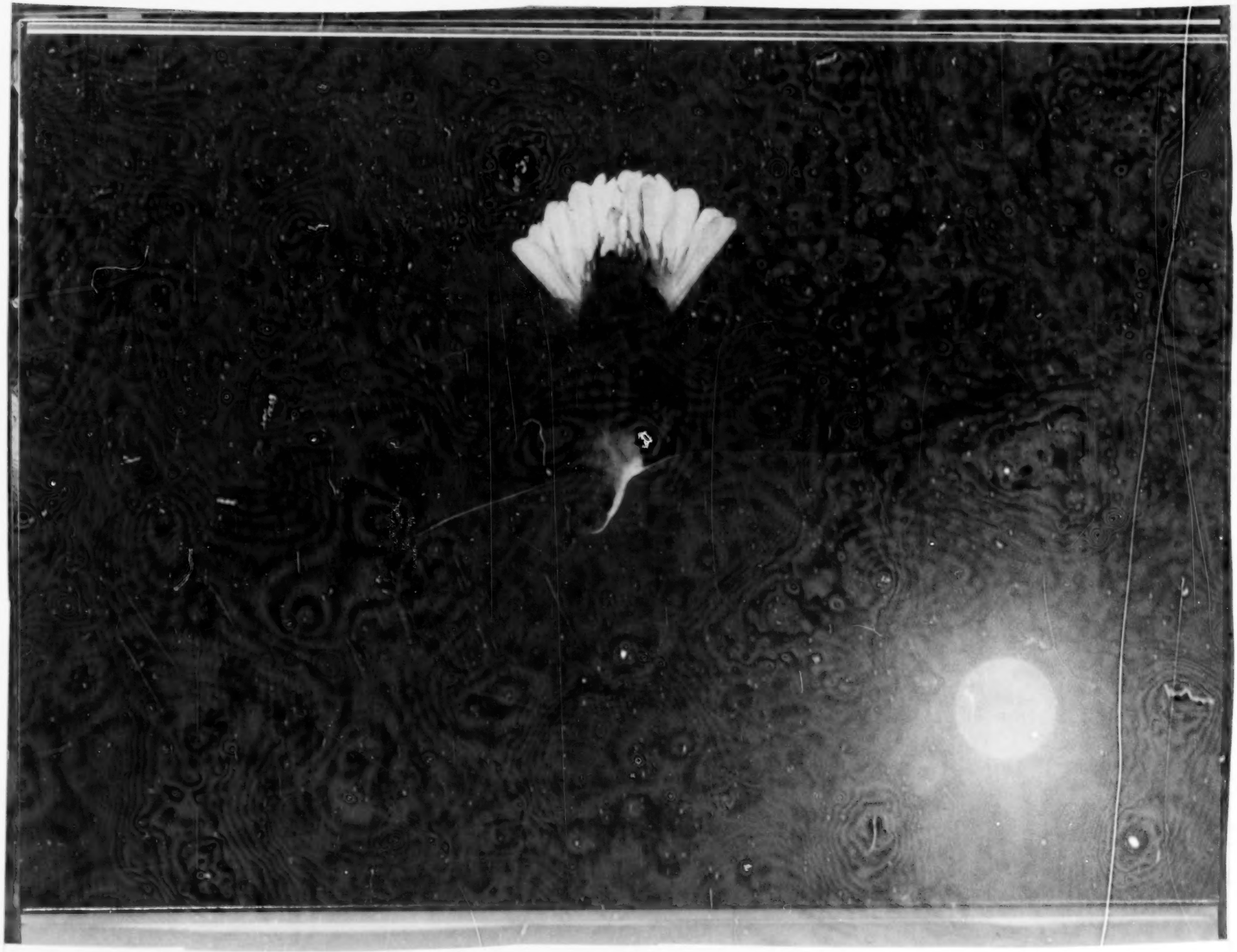

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Circle Reader Action No. 407

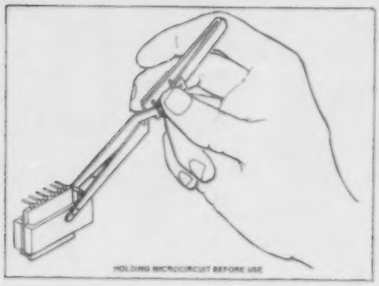
New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing to the NASA Scientific and Technical Information Facility, Technology Utilization Office, P.O. Box 8757, BWI Airport, MD 21240 (see page 21). NASA's patent-licensing program to encourage commercial development is described on page 22.

Holder for Tinning Microcircuit Leads

A heat-sinking tool holds microcircuits for lead tinning while protecting the circuits from heat of the tinning solder. The tool includes two open-box-shaped holders that grip the microcircuit. The leads to be tinned protrude from the gap between the holders. The holders are on the ends of a pair of tweezers that are squeezed open to grasp the microcircuit. As the finger tension is released, the holders close firmly around the microcircuit. The leads are then fluxed and dipped into the solder.

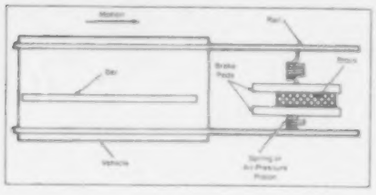
(See page 136.)



Emergency Brake for Tracked Vehicles

An emergency caliper braking system automatically stops a vehicle running on a track whenever the vehicle is in danger of traveling beyond the required stopping point. If the vehicle is about to travel past this point, a bar on the underside of the vehicle dislodges a slippery polytetrafluoroethylene-coated spacer block from etween the brake pads mounted on the track rails (see figure). The brake pads, continuously energized by spring or air pressure, grip the bar, decelerating the vehicle. The operation of the brake triggers a pressure-activated switch on the air-pressure supply or a limit switch on the brake pads, or both, which sends a signal to shut off the vehicle power. The system may be useful on elevators and amusement rides and in mines and heavy industries.

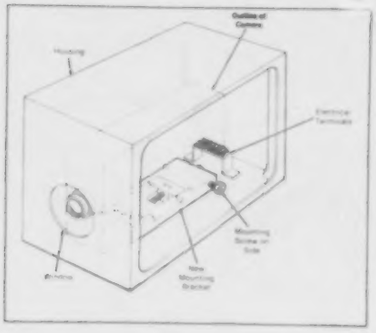
(See page 118.)



Easily Accessible Camera Mount

A modified mount significantly reduces the time required to install high-speed instrumentation movie cameras in explosionproof housings. In the previous mount, the positioning of the mounting screw at the rear left little room between the camera and the housing for the installer's fingers to tighten the screw to secure the camera. Consequently, the tightening was often inadequate, in which case the camera would come loose from vibrations and produce blurred images. With the modified mount, the screw is on the side, readily reachable through the side door of the housing. A right-angle drive mechanism containing two miter gears that turn a threaded shaft alines the camera in the housing and secures it.

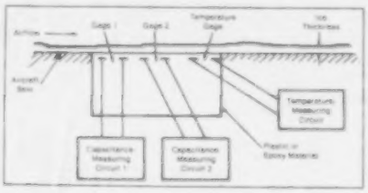
(See page 99.)



Ice Detector for Aircraft

A three-gauge device detects and measures the thickness of ice and water on aircraft skin. This information can serve as a warning to pilots to take appropriate measures for ice removal, either by heating the skin or by changing flight speed or elevation. One gauge of the ice detector determines just the presence of ice and water. Another gauge determines the electrical capacitance of such deposits, the capacitance being directly related to the thickness of the layer. The third gauge measures the temperature of the deposit to sense whether the skin is covered by ice or water.

(See page 100.)



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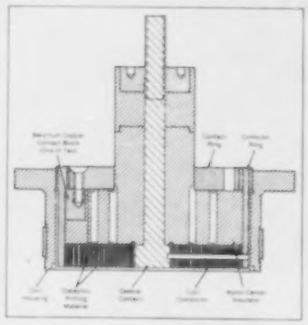
Electromagnetic Hammer for Metalworking

An electromagnetic hammer that can generate momentary pressures up to 5×10^4 psi (3.4×10^8 N/m^2) requires no dynamic material contact with the metal workpiece; consequently, it produces almost no change in the metal grain structure. The desired deformation of the metal workpiece results from the magnetic repulsion between surging electric currents in the work coil of the hammer and thereby induced eddy currents in the part of the workpiece facing the coil. The coil (see figure) is a spirally wound conductor of beryllium copper with polytetrafluoroethylene spacers between its turns, and the coil currents result from the rapid discharge (by a switching device) of an energy-storage capacitor charged to a predetermined value. The coil is mounted in a holder that allows the coil to be kicked back by the magnetic repulsive force and to be repositioned simply by being slid back toward the workpiece.

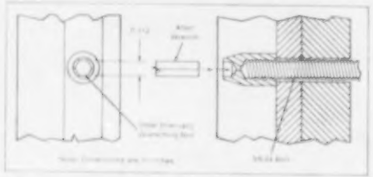
(See page 128.)



Internally Wrenching Nut

Parts in spaces inaccessible from sides by ordinary wrenches and in spaces too crowded to accommodate conventional nuts on projecting bolts can be tightened by a nut torqued by an allen wrench. The new nut is tightened to a bolt from the front (see figure). The new nut should have many uses in assemblies where space is limited, especially in cars and aircraft.

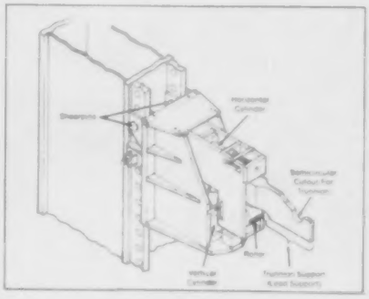
(See page 93.)



Transfer Mechanisms for Heavy Loads

Hydraulically-driven load-bearing mechanisms that produce small motions to emplace or remove heavy loads for transport may be useful in transferring large modular loads in railroads, agriculture, shipping, manufacturing, and garbage collection. The upper mechanism (see figure) in each two-mechanism set lifts the load and moves it horizontally. It supports loads of up to 39 klb (173 kN) and exerts a horizontal force of as much as 16 klb (71 kN) toward or away from the beam on which the mechanisms are held in position by shearpins through holes located at 10-cm intervals. The lower mechanism pushes or pulls horizontally but allows free vertical motion over a limited range. The ranges of the vertical and horizontal motions are sufficient to allow supports to be retrieved from under the heavy loads.

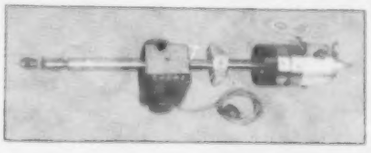
(See page 108.)



Rotating Drive for Electrical-Arc Machining

A rotating drive improves the shape of holes cut by an electrical arc. The holes are more nearly circular, the sides more nearly parallel to hole axes, in comparison to holes formed by ordinary electrical-arc machining. This drive simply rotates the electrode as an electrical drill, while the arc burns off the metal in the workpiece to form a hole. Alternatively, the electrode can be stationary and the workpiece rotating.

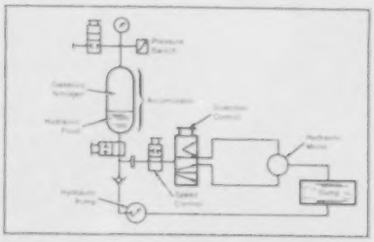
(See page 120.)



Portable Hydraulic Powerpack

A proposed rechargeable hydraulic powerpack would function as a lightweight, compact source of mechanical energy, that could power wheelchairs, drills, winches, and other equipment in areas that have no electricity, or replace electric and internal-combustion motors in explosive environments. Initiated by a small hammer, a chemical reaction occurring in a solid charge would produce hot gas at a safe rate. This gas would drive a turbine pump that pressurizes the hydraulic fluid in an accummulator; the pressurized fluid then could be used to do work on demand. Possible candidates for the solid charges are a combination of rubber and ammonium nitrate, and a mixture of sodium azide and copper oxide.

(See page 115.)



Flex Circuitry for Confined Spaces

Circuits preassebled on flexible wiring facilitates the installation of electronic equipment in confined spaces. The principal circuit elements — including mother boards, printed-circuit-board connectors, large bypass capacitors, and interface connectors are mounted on a flexible polyimide base containing nine layers of embedded copper-foil conductors. After the assembled flexible circuit has been visually inspected and tested for dielectric strength, insulation resistance, and continuity, all exposed connections are coated for electrical and mechanical protection. These flexible circuits eliminate the need for in-place hardwiring and allow smaller enclosures to be used.

(See page 52.)

WELDED AND FORMED BELLOWS ASSEMBLIES

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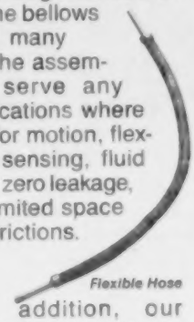
Mechanical Seal



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Pressure Sensor/Actuator

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Volume Compensator

Thrust Control Bellows Assembly

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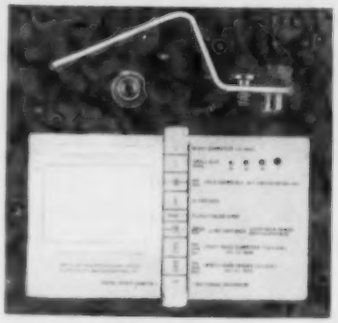
Jig for Removing Rivets

A simple jig helps in drilling out rivets without damage to the surrounding material. The jig has a bushing with a base contoured to match a rivet head. The bushing is inserted into a hole in the jig handle and held in place by an adjacent screw that mates with a notch in the bushing. The operator places the bushing over the rivet with one hand and guides the drill through the bushing with the other. The bushing maintains the proper drilling direction along the rivet axis, preventing the incursion of the drill bit into the adjacent material. The rivet material that remains after drilling is scraped away.

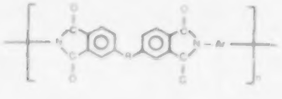
(See page 113.)



Colorless Polyimide Containing Phenoxy-Linked Diamines

Aromatic condensation polyimide films containing phenoxy-linked diamine monomers are essentially transparent in the visible spectral range and possess the toughness, flexibility, low density, thermal stability, radiation resistance, and mechanical strength of the commercial, bright yellow, aromatic polyimide film. These optically transparent/achromatic films should prove highly useful as film and coating materials for use on antennas, solar cells, thermal-control coatings, and other applications requiring high transparency with thermal stability. The production of these transparent polyimide films requires purification of both aromatic diamine and aromatic dianhydride monomers and the solvent used as a medium, and the introduction of phenoxy or thiophenyl "separator" groups and isomeric diamines into the polymer structure.

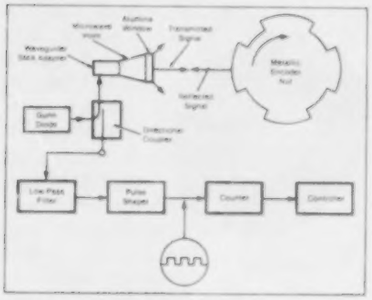
(See page 87.)



Microwave Sensor Measures Turbopump Speed

A microwave sensor measures rotational speed of a turbopump nonintrusively, even when the pumped fluid cavitates. In contrast, a magnetic or capacitive speed sensor protrudes into the flow near the rotating shaft, whereas nonintrusive optical speed sensors do not operate correctly during fluid cavitation. In the microwave speed sensor (see figure), a microwave signal from an antenna in the pump housing is reflected from a lobed, reflective encoder nut on the rotating shaft and returned, modulated by the reflections from the passing lobes, to the antenna. The returned signal is detected and low-pass filtered to extract the modulation. The modulation frequency is proportional to the rotational speed.

(See page 67.)



Pressure-Sensitive Resistor Material

A resistor in which resistivity decreases smoothly with increasing pressure is a promising candidate as a tactile sensor for robots and remote manipulators. The sensor consists of such particles of relatively low conductivity as antimony, silicon, magnetite, nodular graphite, or compound semiconductors embedded in rubber; e.g., room-temperature-vulcanizing silicone or castable urethane. The resistance of the sensor decreases by about 100 times as the pressure on it increases from 0 to 0.8 MN/m^2. For maximum resistance change, the embedded particles should be coarse, one-quarter to one-half the thickness of the sensor; uniform in size and shape; angular; hard; and resistant to wear. The rubber matrix should wet the surface of each particle as little as possible to prevent the resistivity from being too high and should have high tear resistance and low mechanical hysteresis.

(See page 86.)

Sorry, Countess, this is one computer where you won't find VADS™!

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Circle Reader Action No. 398

Electronic Components & Circuits

Hardware, Techniques, and Processes

32 Microstrip Antenna Generates Circularly Polarized Beam
34 Improved High/Low Junction Silicon Solar Cell
38 Increased Spectral Response for Charge-Coupled Devices
40 Submicron Silicon MOSFET
42 Buried-Dielectric-Microstrip Network
44 Brush-Type Connectors for Thermoelectric Elements
47 Phase-Locked Laser Array With Nonuniform Spacing
48 Ultrasonic Bonding to Metalized Plastic
48 Microwave Antenna With Reduced Noise Leakage
50 Pulsed-Corona Electrostatic Charger
51 Calculating Directivities of Planar-Array Antenna Feeds
52 Reliable One-Shot Separation of Connectors
52 Flex Circuitry for Confined Spaces
53 Improved Solar-Cell Tunnel Junction
54 Advanced IPV Nickel/Hydrogen Cell

Microstrip Antenna Generates Circularly Polarized Beam

Higher order modes are excited to produce conical radiation patterns.

NASA's Jet Propulsion Laboratory, Pasadena, California

A circular microstrip antenna excited with higher order transverse magnetic (TM) modes can generate circularly polarized, conical radiation patterns. It has been

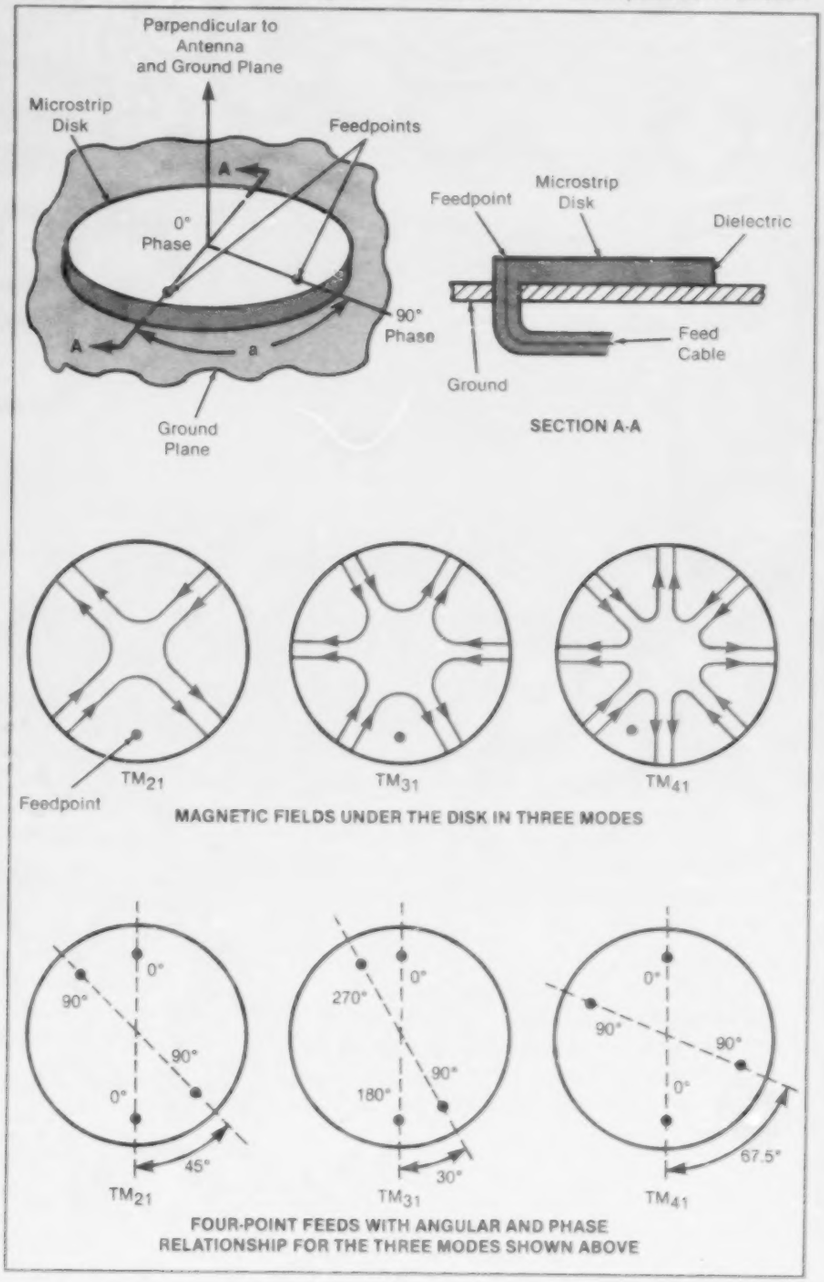

Figure 1. A **Microstrip Disk Antenna** is excited with two spatially and temporally orthogonal electromagnetic fields of a higher order $TM_{\phi r}$ mode (where ϕ and r represent the azimuthal and radial mode order, respectively). Shown here are examples of modes and the feeding arrangements needed to produce them.

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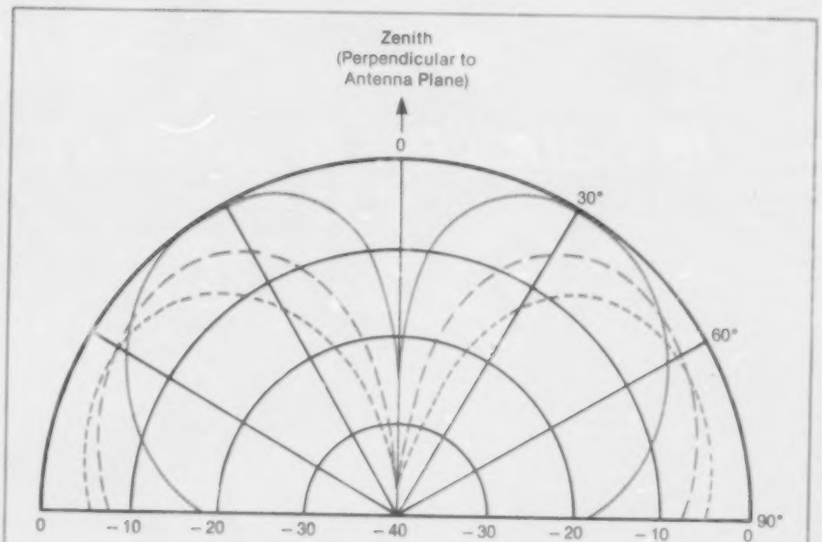
found both theoretically and experimentally that the peak direction of the radiation pattern can be varied within a wide angular range by a combination of mode selection and loading the substrate with materials of different dielectric constants.

To obtain circular polarization, one should use two feeds that differ in temporal phase by 90°. The feeds are located on the disk at the radius for best impedance matching. The angular spacing between the feedpoints is chosen so that the two electromagnetic fields produced by the two feeds are perpendicular to each other both under and over the disk. An additional advantage of this angular spacing is that one feedpoint lies in the null field region of the other feedpoint, with consequent minimization of undesired coupling between the feeds.

To preserve beam symmetry and minimize cross polarization, the user should suppress the unwanted modes. The two modes adjacent to the design resonant mode usually have the next highest amplitudes, but these modes are suppressed by placing two additional feeds diametrically across from the two original feeds. The required temporal phases of the four feeds are then 0°, 90°, 0°, and 90° for the even modes and 0°, 90°, 180°, and 270° for the odd modes. Several modes and four-point feeding arrangements are shown in Figure 1.

For a substrate of a given dielectric constant, an increase in the resonant-mode order causes an increase in the cone angle; that is, the radiation peaks along a cone that lies closer to the plane of the antenna. For a given mode, an increase in the dielectric constant also results in an increase of the cone angle. Figure 2 shows that several combinations of mode and dielectric constant can be selected to obtain peak-radiation (cone) angles ranging from 35° to 69° from the perpendicular to the antenna plane.

A phased array of circular microstrip antennas for directional scanning can be formed by placing such antennas side by side with a spacing of a half wavelength (in air, not in the dielectric). Because the resonant diameter of a disk for a higher order mode is usually larger than half an air wavelength, it is often impractical to form such an array. However, the resonant disk size is reduced by increasing the dielectric constant. In the TM_{21} mode, for example, a disk with a substrate dielectric constant of 4.2 would have a half-wavelength resonant diameter. A triangular lattice of antenna elements of this kind could be used for electronic scanning between about 10° and 70° above the horizon with little degradation in gain due to element pattern.



	Mode	Relative Dielectric Constant	Peak Direction From Zenith	Radiator Diameter in Vacuum Wavelengths
———	TM_{21}	1.25	35°	0.9
— — —	TM_{31}	2.2	54°	0.93
– – – – –	TM_{41}	4.2	69°	0.88

Figure 2. **Calculated Radiation Patterns** are plotted for three different combinations of modes and dielectric constants.

This work was done by John Huang of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 19 on the TSP Request Card.*
NPO-16460

Improved High/Low Junction Silicon Solar Cell

The air-mass-zero open-circuit voltage is increased to 650 mV.

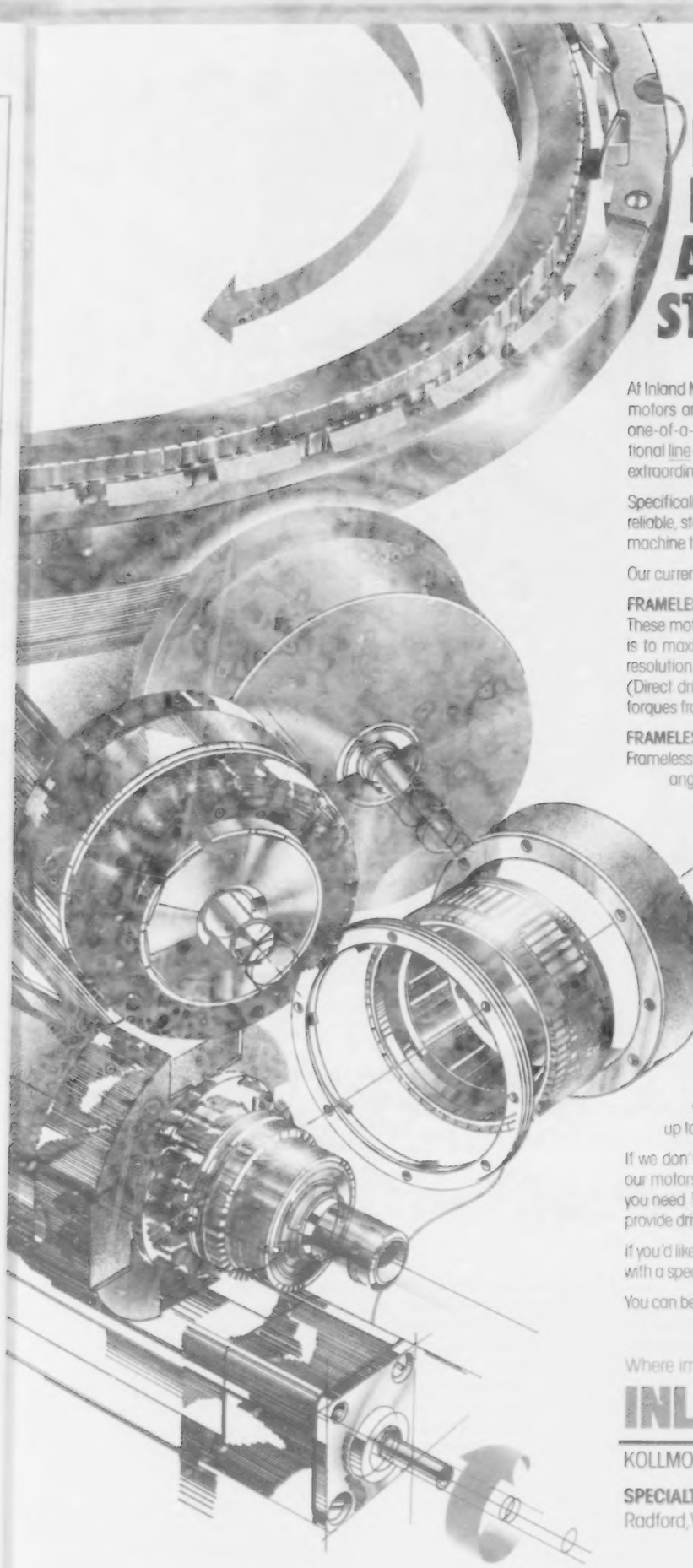
Lewis Research Center, Cleveland, Ohio

A method has been developed to raise the value of the open-circuit voltage in silicon solar cells by incorporating a high/low junction in the cell emitter.

The power-conversion efficiency of the low-resistivity silicon solar cell is considerably less than the maximum theoretical value mainly because the open-circuit voltage is smaller than simple p/n junction theory predicts. With this method, the air-mass-zero open-circuit voltage has been increased from the 600 mV level to approximately 650 mV.

The figure gives a cross-sectional schematic view of the proposed cell. Shown is the p-type substrate and the n-type emitter comprising a low region and a high-electron-accumulation region. An oxide layer on the illuminated surface contains a high positive charge. Shallow n^+ contact diffusion regions underlie each of the one or more aluminum emitter contacts, and an ohmic contact underlies the p region.

A p/n junction exists between the emit-



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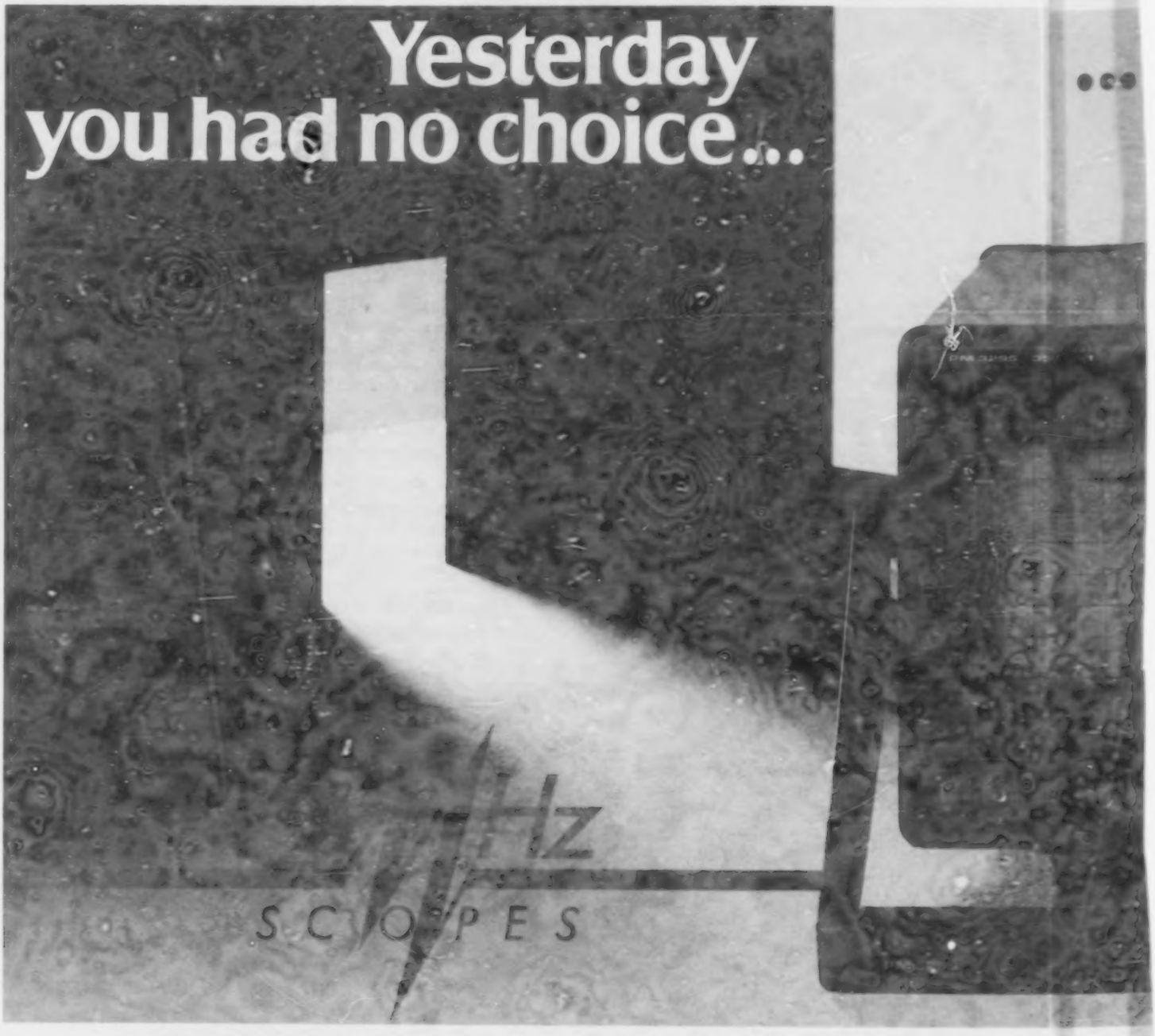

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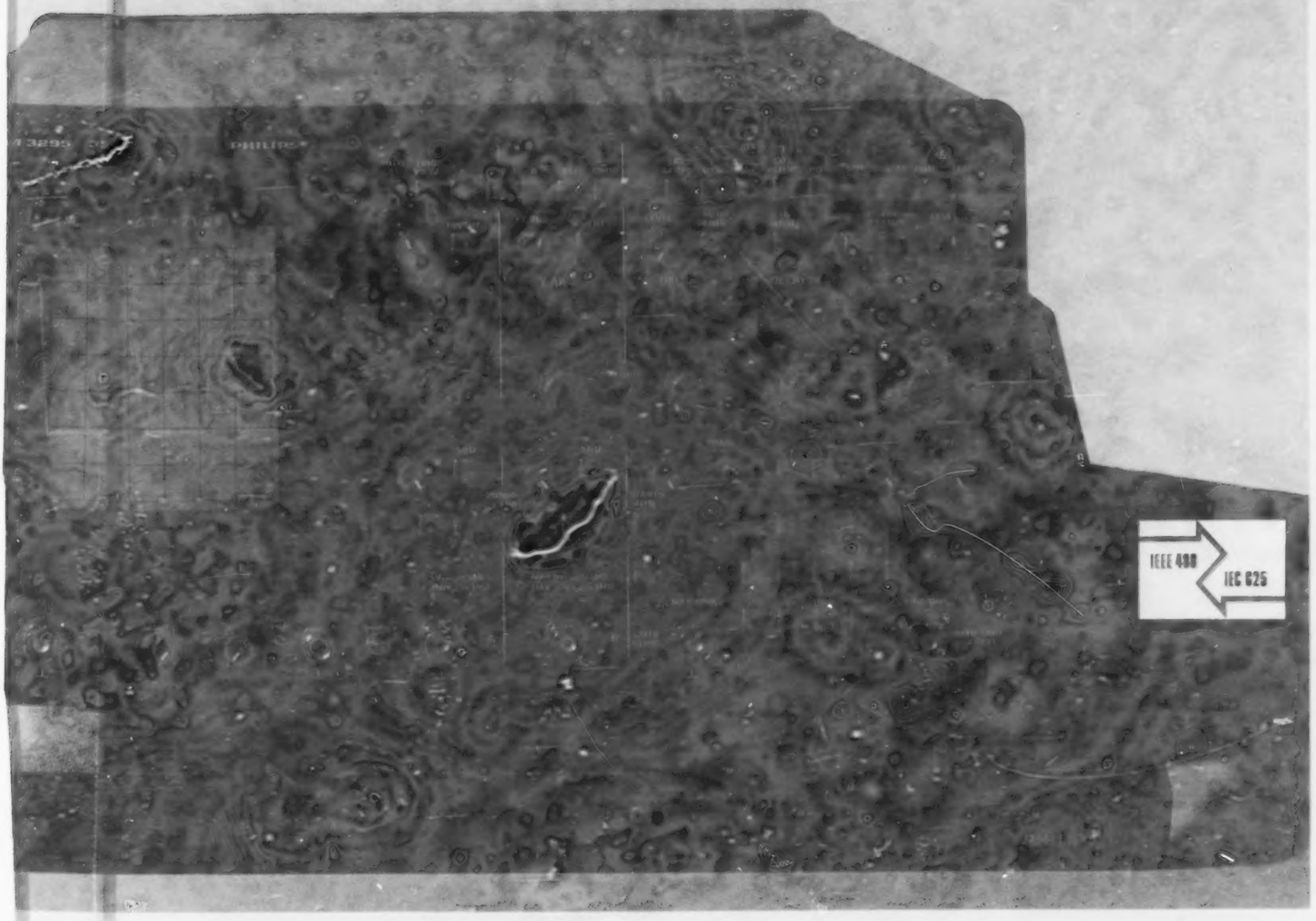

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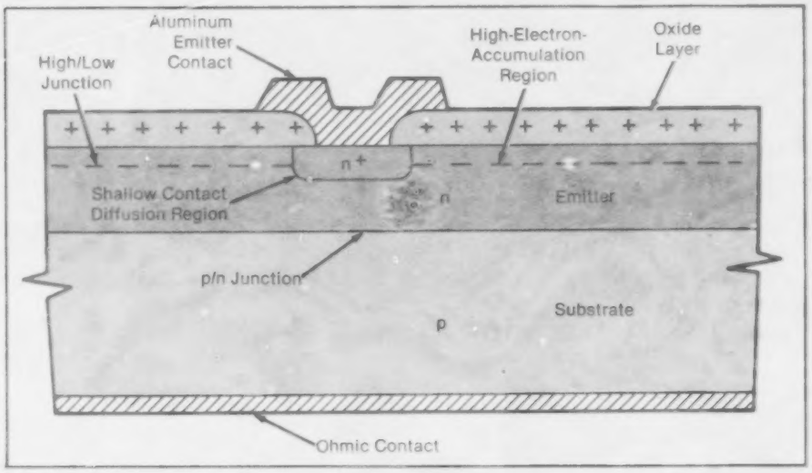


ter region and the substrate. A high/low junction has been formed between the high-electron-accumulation region and the low emitter region. An aluminum metal contact is in ohmic contact with the emitter, and a shallow n^+ diffusion contact is made under this metalized portion of the top surface area. The aluminum emitter contact covers no more than 5 to 10 percent of the surface area.

Provided in the proposed solar cell is a suppression of dark emitter current and an increase of short-circuit current. The emitter is less heavily doped — preferably in the $\sim 10^{18}$ to 10^{19} cm^{-3} range — compared to emitters of conventional cells, which are typically doped to about 10^{20} cm^{-3}. A heavily doped emitter region has the disadvantage that the dark emitter recombination is so large that it limits the maximum open-circuit voltage to about 600 mV. The high/low emitter suppresses the dark emitter recombination current, resulting in power-conversion efficiencies significantly higher than were previously achieved.

This work was done by Arnost Neugroschel, Shing-Chong Pao, Fred A. Lindholm, and Jerry G. Fossum of the University of Florida for **Lewis Research Center.** *Further information may be found in "Emitter Current Suppression in a High-Low-Junction Emitter Solar Cell Using an Oxide-Charge-Induced Electron Accumulation Layer," A. Neugroschel, F. A. Lindholm, S. C. Pao, and J. G. Fossum, Applied Physics Letters, 33(2), 15 July 1978. Copies are available from the NASA Scientific & Technical Information Facility, P. O. Box 8757, Baltimore/Washington International Airport, MD 21240.*

Inquiries concerning rights for the commercial use of this invention should be addressed to Patent Counsel, Lewis Research Center [see page 21]. Refer to LEW-13618.

Increased Spectral Response for Charge-Coupled Devices

Spectral response was determined from 1 to 11,000 Å.

NASA's Jet Propulsion Laboratory, Pasadena, California

Significant improvement in charge-coupled-device (CCD) spectral sensitivity was demonstrated over a remarkable range of 1 to 11,000 Å. The improvement in quantum efficiency, in conjunction with the CCD low-read-noise floor (<4e⁻), opens up new scientific opportunities in the fields of biology, nuclear science, laboratory plasma diagnostics, and a host of other physical and astronomical applications in the UV, X-UV, and X-ray regimes. Figure 1 shows the best response that has been achieved to date, covering the soft X-ray to the near infrared.

The improvement in extending the spectral response of the CCD has come from proper preparation of the absorbing surface, in conjunction with charging the surface before use. Charging, which can be performed using ultraviolet flood, corona charging, or nitrogen monoxide gas, provides an ideal accumulation layer with the appropriate electric field to sweep minority carriers photogenerated at the back side into the front-side CCD depletion wells (see Figure 2).

This work was done by James R. Janesick and Tom Elliott of Caltech for

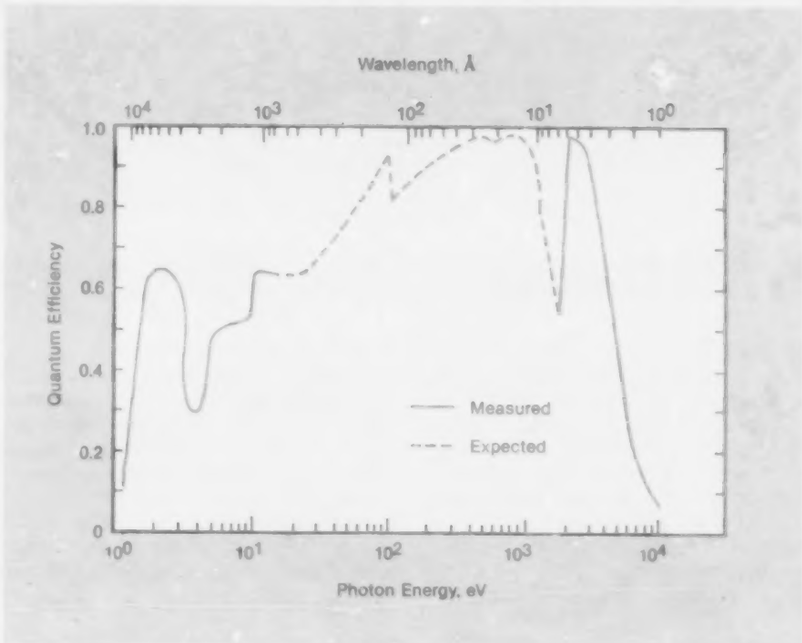
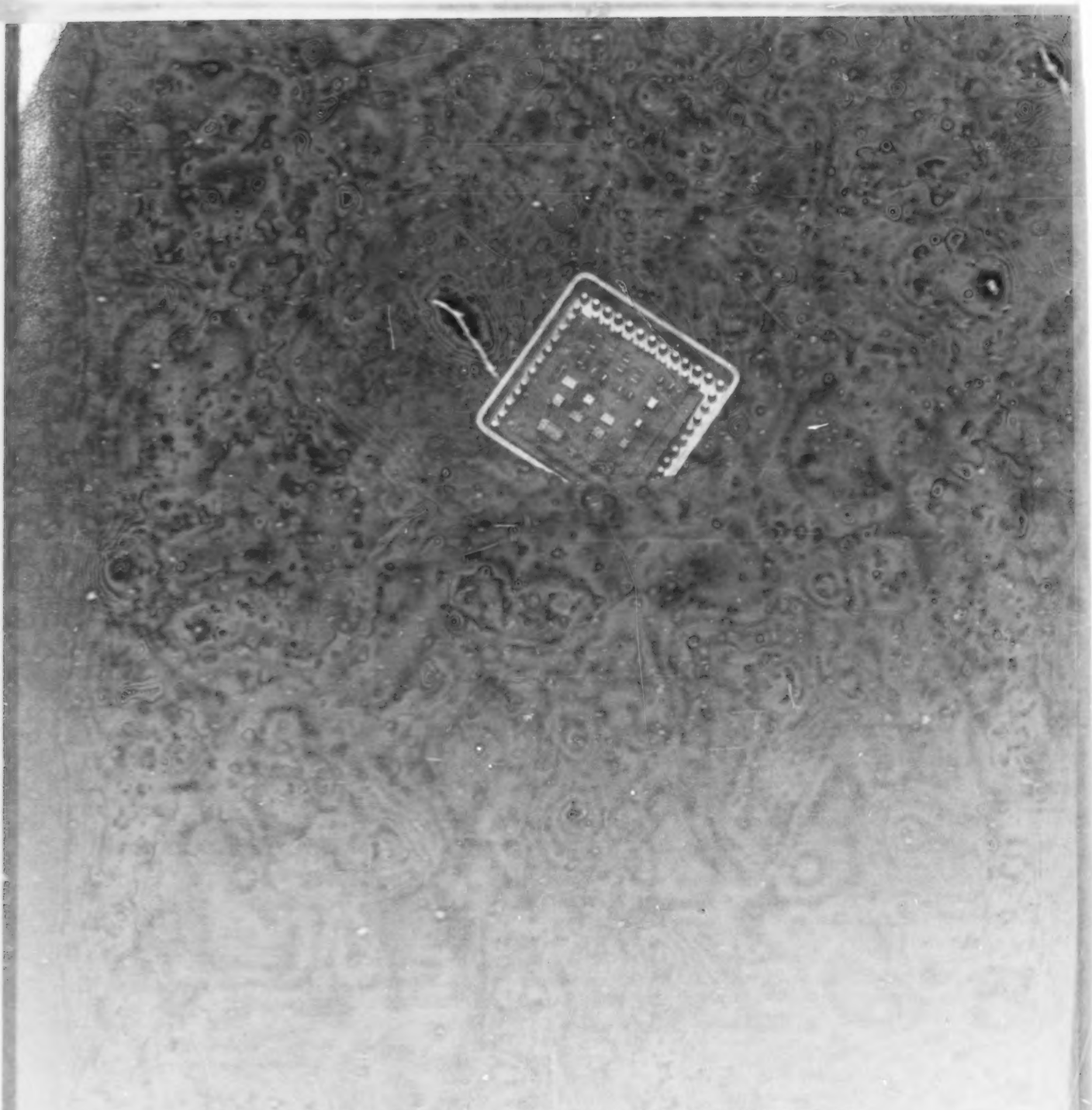


Figure 1. The **Spectral Response of a CCD After UV Flooding** indicates that the measured data correspond closely to theoretical performance, lending credence to the unmeasured portions of the curve.



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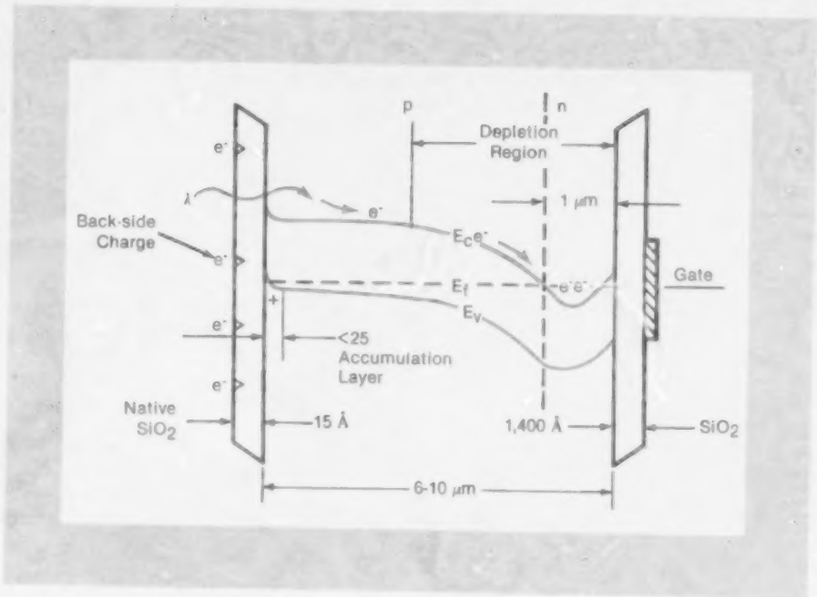


Figure 2. The **Potential Profile of a CCD** that has been thinned and UV-flooded produces a local field. This field directs the photogenerated charge toward the front-side potential well.

Submicron Silicon MOSFET

Gate length could be only a few hundred angstroms.

NASA's Jet Propulsion Laboratory, Pasadena, California

A suggested process for making metal-oxide/semiconductor field-effect transistors (MOSFET's) would result in gate-channel lengths of only a few hundred angstroms — about 100 times as small as those of state-of-the-art devices. Gates must be shortened to develop faster MOSFET's; the proposed fabrication process would be used to study the effects of size reduction in MOS devices and perhaps eventually to build practical three-dimensional structures.

The process requires a substrate of single-crystal [100] low-resistivity, n-type silicon. By molecular beam epitaxy or another suitable technique, lightly-doped p-type silicon would be deposited on the substrate to a thickness of 200 to 500 Å. A 1-μm heavily-doped n-type layer would be deposited on the p-type layer.

A V-groove would be formed through the layers (see Figure1) by anisotropic etching. An oxide layer would then be formed and metal deposited by conventional photolithography. No intricate submicron lithography is involved.

The proposed MOSFET structure may be deficient in two respects: First, the thin oxide may tend to break down in the source and drain regions at voltages high enough to turn a device on. Second, the large source-to-gate and source-to-drain capacitances caused by the thinness of the oxide may limit device speed. A possible remedy (see Figure 2) may be to increase the oxide thickness in the source region so that the gate metal lies in proximity to the p-type gate material only.

This work was done by Taher Daud of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 51 on the TSP Request Card.*
NPO-16601

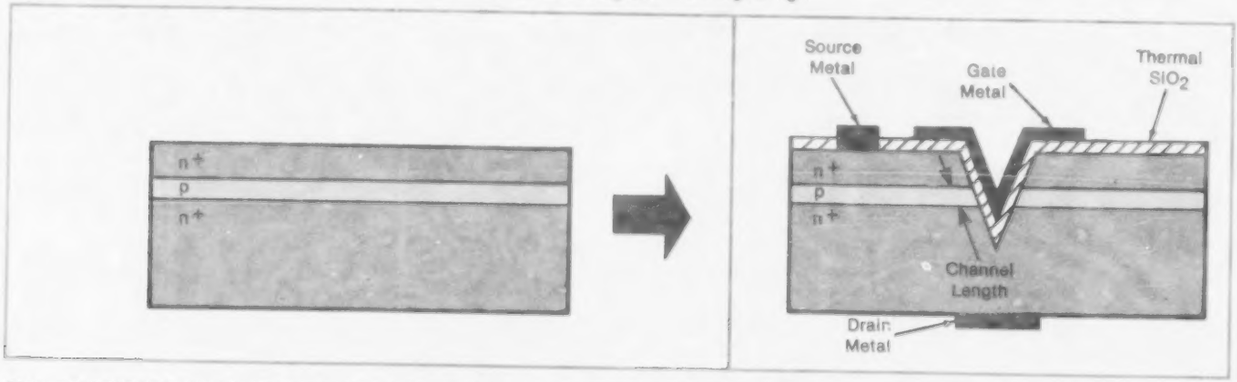
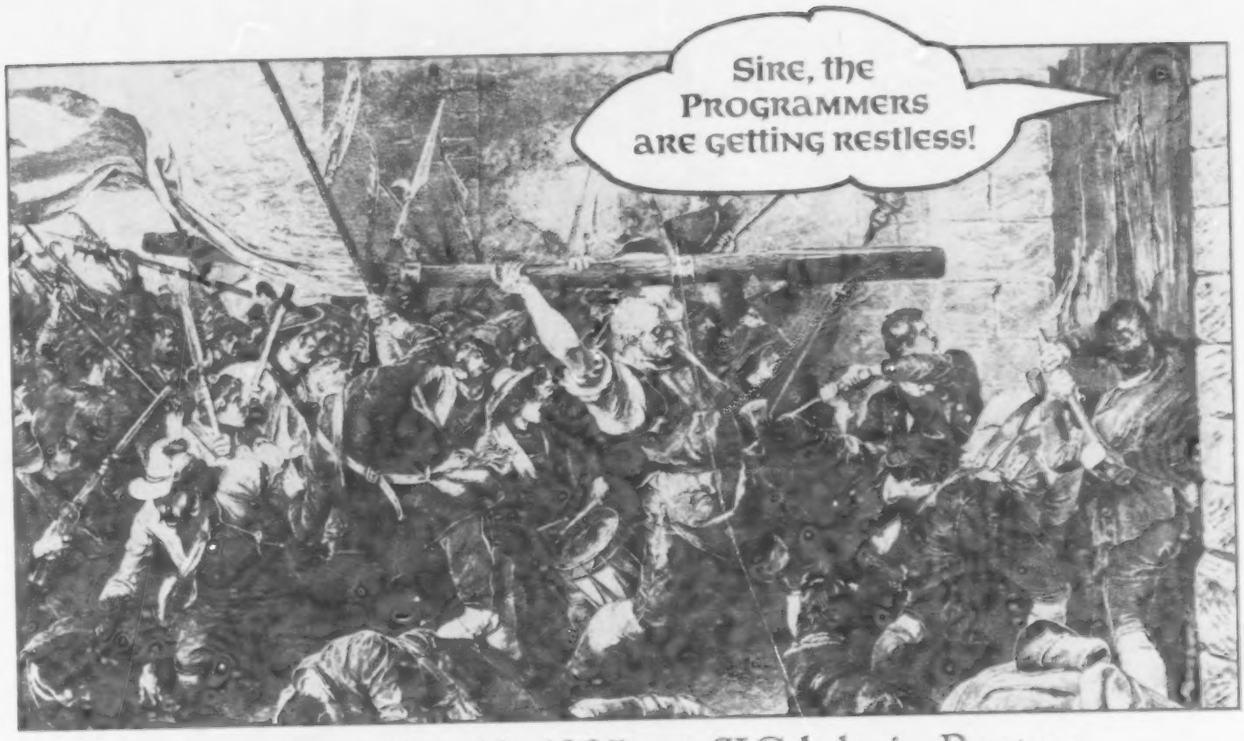


Figure 1. A **MOSFET Would Be Formed** by etching a V-shaped groove through semiconducting layers, then depositing an oxide insulating layer and metal contacts.



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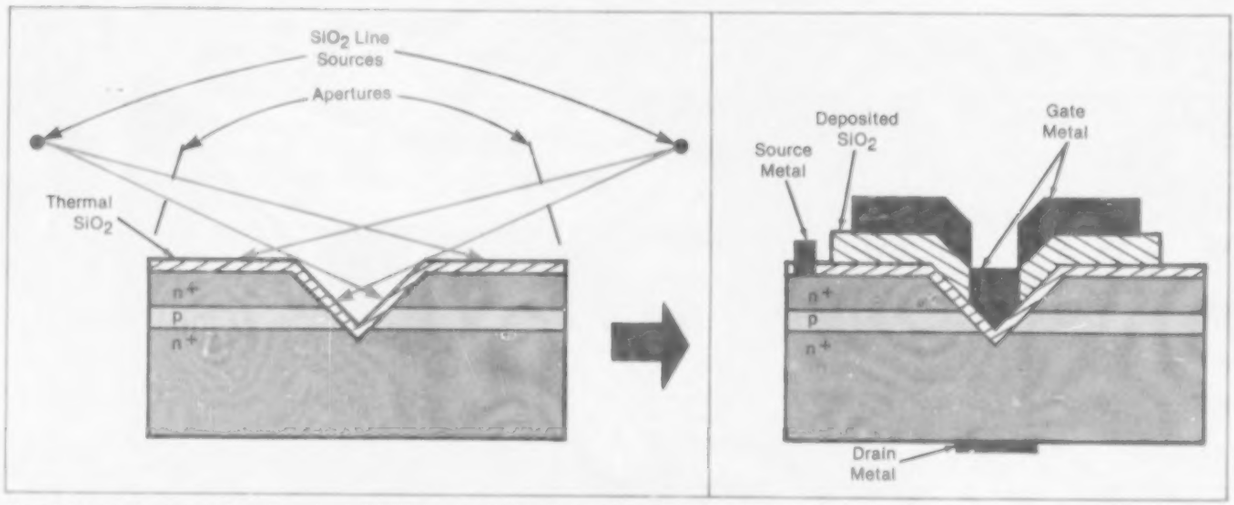


Figure 2. In an **Improved Version of the MOSFET,** two SiO_2 line sources would be used to form a thick oxide layer over the thermal oxide, which acts as a self-alined mask. The gate metal would be deposited from a source aimed perpendicularly to the surface. Standard fabrication techniques would be used. High accuracy would be required only in controlling the oxide thickness.

Buried-Dielectric-Microstrip Network

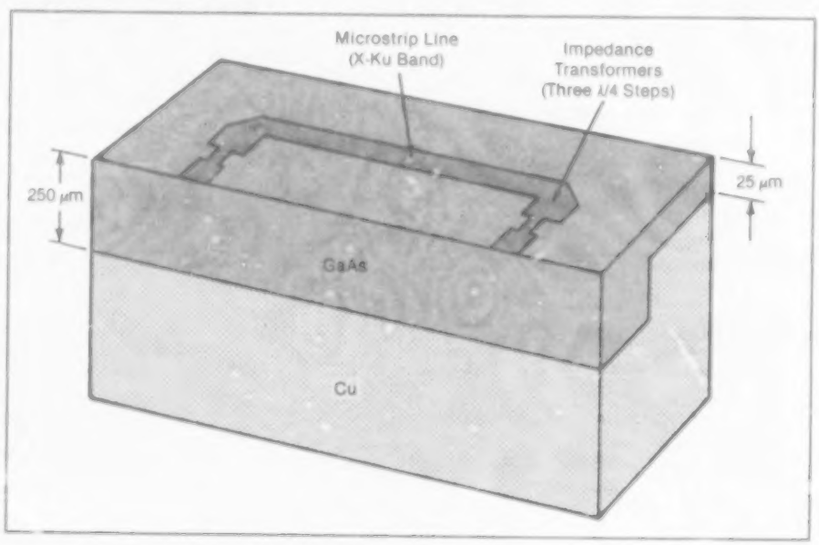
A three-dimensional matching network is fabricated on a GaAs thin-film waveguide.

Langley Research Center, Hampton, Virginia

Continuous tuning of a CO_2 laser by phase modulation at microwave frequencies in GaAs thin-film waveguides has been reported previously. In optical waveguides, extremely-intense optical and microwave fields can be established, provided that special techniques are used to couple optical and microwaves efficiently into the device. If these two kinds of waves are properly synchronized with nearly-the-same phase velocity, very efficient and broadband modulation can be achieved. Phase modulation of CO_2 lasers at microwave frequencies generates both the upper and lower sideband frequencies, which can be well resolved from the laser carrier frequency. By varying the microwave frequency, one can tune the sideband power over a certain range. The tuning range depends critically on the modulator structure.

One of the problems in previous work has been in obtaining very-broadband and uniform frequency response. The problem was resolved with a buried-dielectric-microstrip matching network incorporated into an infrared-waveguide structure. This waveguide modulator structure represents the state-of-the-art of integrated optical devices. It has a three-dimensional shape to accommodate three quarter-wavelength-transformers for microwave impedance matching at both the input and output terminals. The microwave network, along with a microstrip line designed with the aid of a computer, has been integrated with the optical waveguide and has been used to tune a line-selectable CO_2 laser that provides a total tuning range of 30 GHz in two sidebands.

To make a microwave tuned-waveguide modulator, one must fabricate an appropriate electrode on a thin slab of GaAs with a metallic ground plane on the surface opposite that of the electrode. The electrode must be properly designed so that the guided infrared wave is synchronized with the traveling microwave to achieve high modulation efficiency. Another consideration in maximizing



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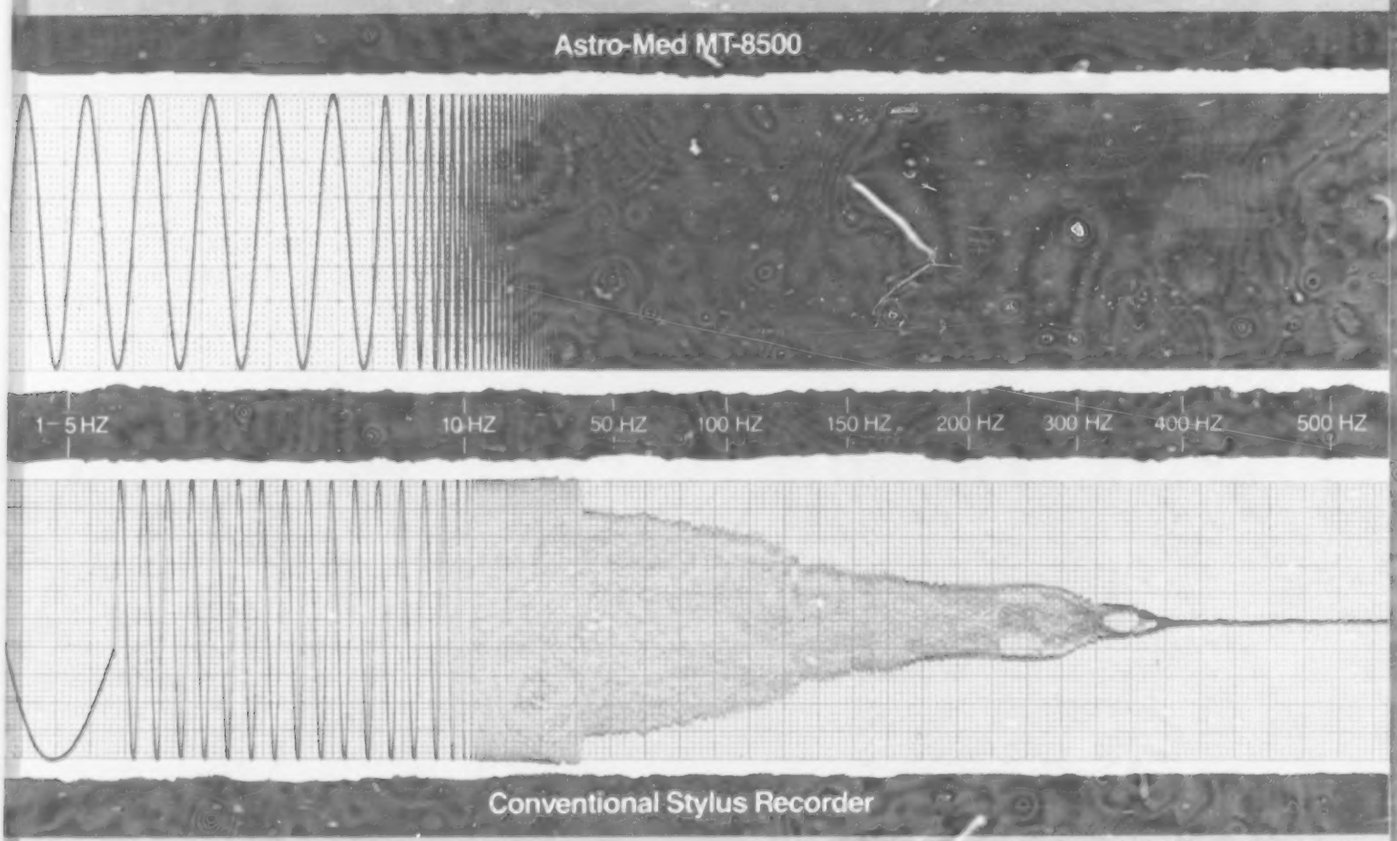

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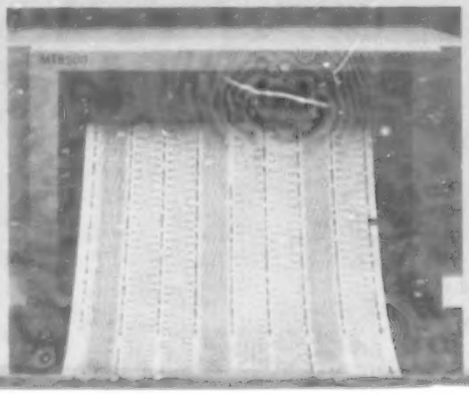

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sideband efficiency is to increase the microwave field in the waveguide by minimizing the microstrip width w and thickness t. The thickness of the microstrip has been reduced to 25 μm; however, optical-coupling considerations currently limit the reduction in microstrip width to 1 mm. The high aspect ratio (w/t = 40) of this microstrip yields a low impedance (2.7 Ω) that must be matched over a broad frequency band to a microwave source and termination.

Microwave energy can be coupled efficiently into a microstrip waveguide modulator provided that several quarter-wavelength-step impedance transformers (see illustration) are used to form a good match between the 50-Ω input impedance and the impedance of the modulator. The impedance of the transmission line can be adjusted by adjustment of the width of the microstrip electrode.

For a thin (25-μm) slab of GaAs, this approach can lead to a serious problem. To match the 50-Ω impedance, one must reduce the electrode width to approximately 25 μm. At this width, the line is very fragile and not suitable for high-power operation. This problem is resolved with a thick (250-μm) GaAs slab integrated into the waveguide structure. With this thicker slab, a wider and more rugged electrode can be fabricated.

The modulator has been experimentally evaluated, and it provides very reliable and reproducible performance. It was developed primarily for remote sensing of the atmosphere, but it can also be used as a convenient and reliable analytical tool for very-high-resolution spectroscopic studies or for such other applications as isotope separation and frequency-multiplex communication. The buried-dielectric-microstrip network that enables the modulator to have state-of-the-art, 30-GHz sideband tunability may also be used to match the impedances of other low-impedance microwave devices over a wide band.

This work was done by P. K. Cheo, R. A. Wagner, and M. Gilden of United Technologies Corp. for **Langley Research Center.** *For further information, Circle 85 on the TSP Request Card.* *LAR-13285*

Brush-Type Connectors for Thermoelectric Elements

Connectors ensure conduction of heat and electricity while accommodating thermal dimensional changes.

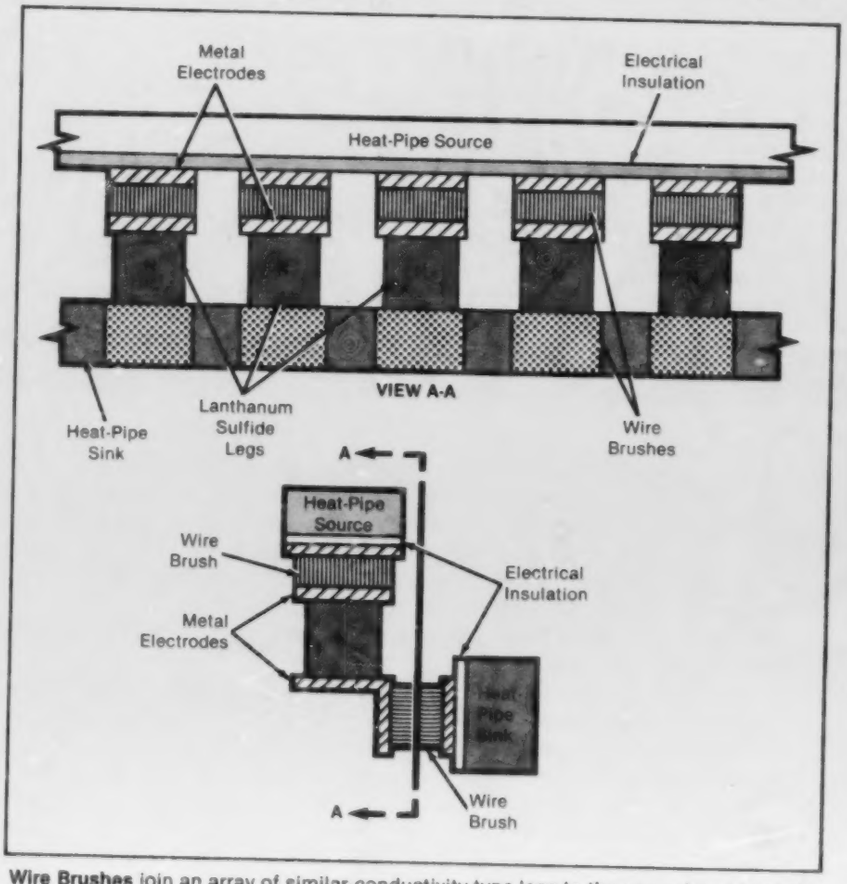
NASA's Jet Propulsion Laboratory, Pasadena, California

Wire brushes can be used to connect the positive and negative legs of semiconductor thermoelectric generators to power leads and to heat sources and sinks. The brushes are flexible thermal and electrical conductors that readily accommodate the expansion and contraction of the legs with changing temperature. Thus, direct conductive coupling between heat source and sink is allowed, in contrast to the older and less efficient method of having to couple radiatively to accommodate thermal expansion.

The electrical and thermal conductions of the brushes, at sufficiently-high wire-packing densities, can approach the magnitudes of solid metal contacts, with a compromise being made between flexibility and conduction properties. The brushes have the additional advantage of being more easily assembled to the legs in large arrays of p- and n-type elements (see figure).

Arrays of boron carbide p-type legs and lanthanum sulfide n-type legs would benefit particularly from the wire-brush connectors. These semiconductors expand with temperature at widely differing rates. Wire brushes of equal thickness could be used for both types of semiconductors and could accept the greatly different expansions of the two semiconductors without being stressed excessively.

This work was done by Charles Wood of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 39 on the TSP Request Card.*
NPO-16545



Wire Brushes join an array of similar-conductivity-type legs to the power bus and to the heat source and sink. An array of p-type legs would be positioned atop the heat-pipe source shown here in the same 90° configuration with a heat-pipe sink.

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Phase-Locked Laser Array With Nonuniform Spacing

A single far-field lobe is obtained.

Langley Research Center, Hampton, Virginia

Multiple-stripe lasers that produce high continuous-wave output powers have been demonstrated. Generally these devices use optical coupling between the stripes to provide for phase-locked operation, which results in stable beam parameters. However, phase-locked injection-laser arrays with well-defined stripes on regular centers tend to configure the relative phase between stripes so that adjacent stripes are operating 180° out of phase. This leads to an undesirable lateral far-field distribution that consists of two lobes symmetrically located about the facet normal with an angular separation determined by the center-to-center separation of the stripes.

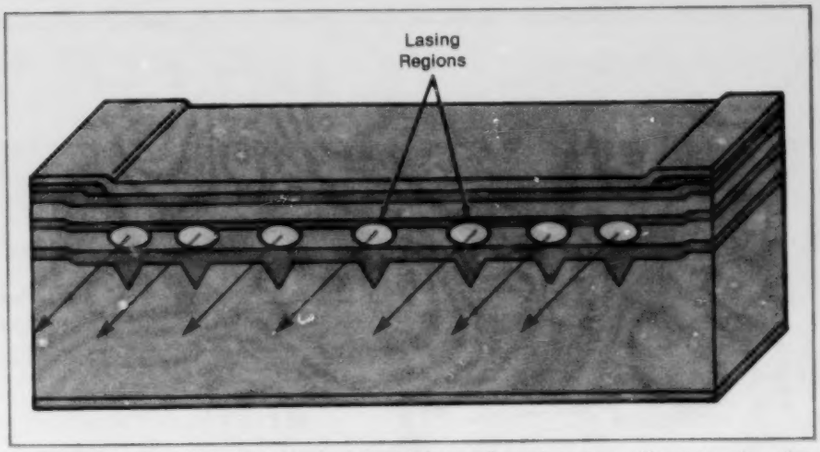
To obtain a phase-locked array that reliably produces a single far-field lobe, a proposed configuration includes lasing stripes that are not placed on regular centers but are located in a regular way with nonuniform centers (i.e., with the spacing determined by some function). Alternatively, the lasing stripes may be placed on a set of periodic arrays with different stripe-to-stripe centers that are interlaced onto a single chip or placed in a structure in which the stripe-to-stripe spacing is random or pseudorandom.

A monolithic, phase-locked, semiconductor-laser array having a variable spacing between the lasing regions has been fabricated (see figure). This design produces an output laser beam comprising substantially a single lobe. The center-to-center spacings between the lasing regions are variable across the array in a lateral direction: They decrease with increasing distance from the centerline. The lasing regions are spaced an effective distance apart such that the laser oscillations in the different lasing regions are phase-locked to one another.

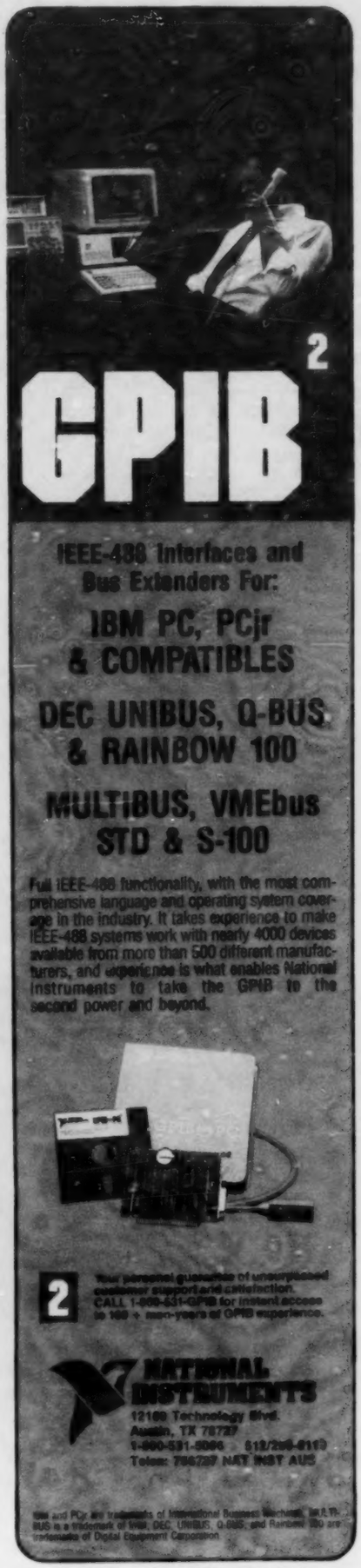
The variable spacing of lasing regions or nonuniform stripe spacing on multiple-stripe lasers will have two important effects. First, depending on the waveguide configuration used, the relative phases between stripes may be altered as the stripe separation changes, leading to modifications of the far-field distribution. Second, since the far-field distribution results from the Fourier transformation of the near-field distribution, the nonuniform spacing will result in a modified far-field pattern. By using these two effects, it should be possible to tailor the stripe separation to produce far fields that are well suited for particular applications.

This work was done by Donald E. Ackley of RCA Corp. for **Langley Research Center.** *For further information, Circle 33 on the TSP Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457 (f)], to the RCA Corp., Princeton, NJ 08540.
LAR-13281



A **Monolithic, Phase-Locked, Semiconductor-Laser Array** has nonuniform spacings between lasing regions. The nonuniform spacing helps to suppress modes in which adjacent lasing regions operate 180° out of phase with each other.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Circle Reader Action No. 348

Ultrasonic Bonding to Metalized Plastic

Unpackaged integrated-circuit chips can be attached to circuit boards.

NASA's Jet Propulsion Laboratory, Pasadena, California

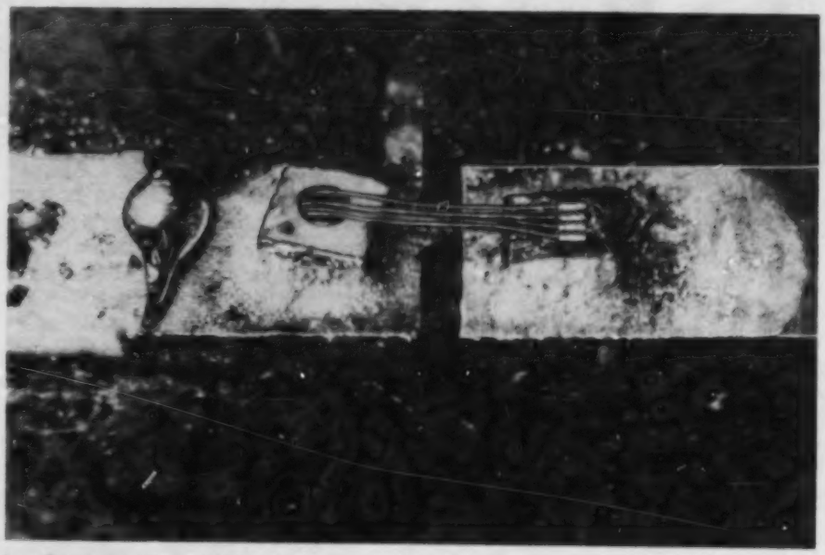
A new technique makes it possible to bond wires ultrasonically to conductor patterns on such soft substrates as plain or ceramic-filled polytetrafluoroethylene. Previously, ultrasonic wire bonding could be used only with conductor patterns on such relatively hard substrates as sapphire, quartz, silica, or alumina.

Until now, ultrasonic wire bonding could not be done on soft substrates because these substrates have dissipated the bonding energy. In the new technique, a gold-plated copper disk is soldered to the circuit board at the point where the ultrasonic bond will be made. The disk concentrates ultrasonic energy at the bonding site so that strong and reliable wire bonds result (see figure).

With ultrasonic bonding, unpackaged chips can be attached to soft circuit boards. Previously, it was necessary to use packaged chips, which can be attached to such boards by solder or by conductive adhesive. The unpackaged chips are preferred because they require less substrate area and are better matched electrically to the circuit board at high frequencies.

This work was done by Bruce L. Conroy and Charles T. Cruzan of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 29 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 21]. Refer to NPO-16087.



In a Demonstration of Ultrasonic Bonding, four fine wires were connected from a microwave component to a bonding disk on a metalized pad on a plastic substrate.

Microwave Antenna With Reduced Noise Leakage

Feed-beam taper reduces rear spillover.

NASA's Jet Propulsion Laboratory, Pasadena, California

The gain or gain-to-temperature ratio of a dual-shaped subreflector receiving antenna is increased when the illumination is tapered near the aperture edge. The taper imposed in the antenna feed reduces spillover in the transmitting mode and reduces noise pickup in the receiving mode.

In a conventional dual-shaped subreflector antenna operating in the transmitting mode, the primary function of the subreflector is to direct more power toward the main-reflector aperture edge. This arrangement makes the illumination more uniform across the aperture, there-

TAPER EXPONENT, p	ILLUMINATION EFFICIENCY, η_I	REAR SPILLOVER EFFICIENCY, η_{RS}	$\eta_I \times \eta_{RS}$	ANTENNA ZENITH NOISE COMPONENT DUE TO REAR SPILLOVER, KELVINS
0 (Uniform illumination)	0.996	0.943	0.939	14
0.25	0.994	0.976	0.970	5.8
0.50	0.973	0.990	0.958	2.3
0.75	0.943	0.996	0.939	1

Calculated Antenna-Performance Characteristics are shown for an antenna with a main-reflector diameter of 1,080 wavelengths and a subreflector diameter of 125 wavelengths, with four different feed-beam tapers.

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by contributing to the gain. The attempt to increase the gain is partly defeated, however, by the spillover, which is the loss of power beyond the edge of the main reflector due to diffraction by the subreflector.

When the antenna is used in the receiving mode, the inward flow of power over the spillover path results in the pickup of undesired signals or thermal noise from the side or rear. For example, if the antenna is aimed toward the zenith, the inward spillover of thermal noise from the ground causes a temperature increase of about 2.4 K in the antenna for each percent of power lost in the transmitting mode.

To reduce the diffraction effect, the aperture illumination pattern is synthesized so that the power density in the main aperture is proportional to

$$\left(1 - \frac{r^2}{R^2}\right)^p$$

where r is the radial distance from the aperture center, R is a length chosen to be somewhat greater than the radius of the aperture edge, and $0 \leq p \leq 1$. The choice of p determines the sharpness of the taper, with $p = 0$ representing conventional uniform aperture illumination. The synthesis of aperture illuminations with tapers like this is known from previous investigations.

A theoretical comparison was made among four tapers in a representative antenna design (see table). The numerical results show that as the taper exponent increases, the illumination efficiency decreases, but there is a compensating decrease in spillover resulting in an increase in spillover efficiency. If gain is the main criterion, then the design with $p = 0.25$ is the best of the four. When the spillover contribution to the antenna temperature is considered, then the design with $p = 0.75$ appears to offer the best performance.

This work was done by Alan G. Cha of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 89 on the TSP Request Card. NPO-15785*

Pulsed-Corona Electrostatic Charger

Small objects can be charged positively or negatively for electrostatic levitation.

NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental charge-generating apparatus can supply nanocoulomb charges to small objects. The purpose of the experiments is to develop a contactless charger for solid or liquid spheroids in contactless (levitation) processing.

The circuit applies high-voltage radio-frequency (RF) pulses to either of two sets of electrodes (see Figure 1). These RF pulses generate a corona between the electrodes in each set, thereby generating ions. The RF pulses are superimposed on a 60-Hz high voltage applied across the space between the two electrode sets. This voltage accelerates the corona ions across the gap toward the opposite set of electrodes. An object placed in the gap intercepts some of the ions and becomes charged. Figure 1 shows a typical charging circuit and a charging head.

To charge the object with positive ions, the RF pulse is applied to a set of electrodes when that set is at or near the positive peak of the accelerating voltage. Alternatively, the set receiving the RF corona burst can be grounded and the burst applied when the other set is at the negative peak of the accelerating voltage. For the most effective positive charging, the accelerating-voltage transformer T_3 is center tapped to ground, and the RF burst is applied alternatively to each electrode set when it is near the positive peak of the accelerating voltage. Of course, the object can be negatively charged by applying the RF pulses at the negative peaks of the accelerating voltage.

Transformers T_1 and T_2 are identical flyback transformers, each capable of a max-

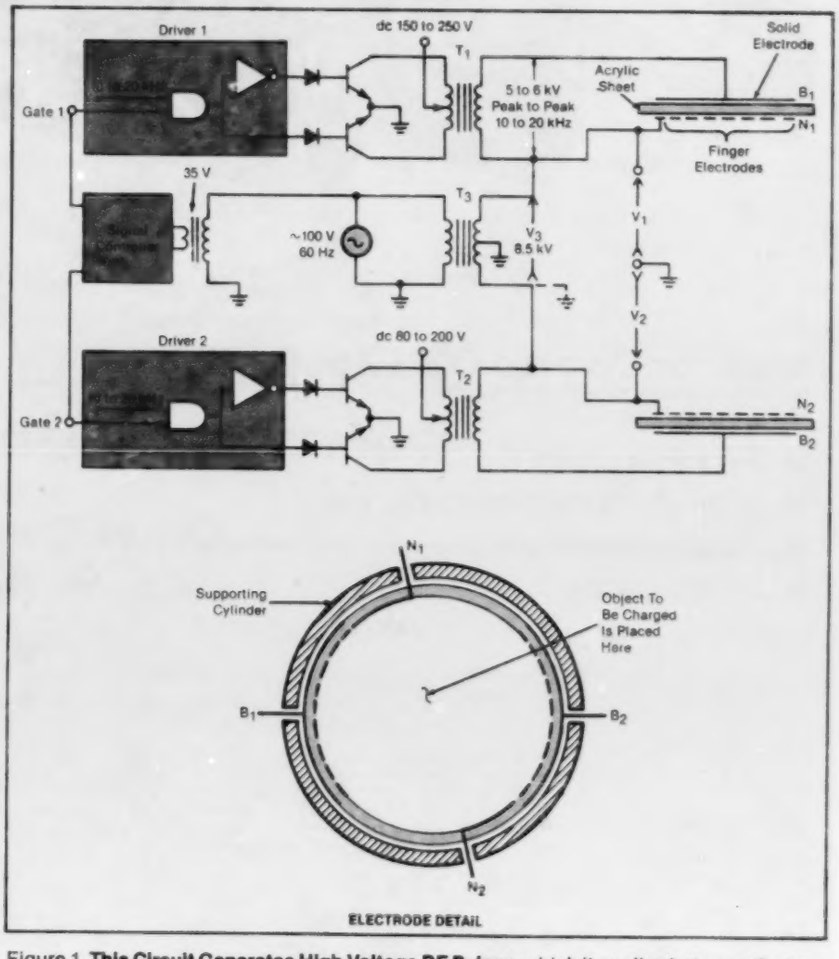


Figure 1. **This Circuit Generates High-Voltage RF Pulses,** which it applies between the two electrodes in each set. It also applies a 60 Hz high accelerating voltage between the two sets of electrodes. The two sets of electrodes are made of conductive paint on acrylic sheets, which are placed diametrically opposite each other in a supporting cylinder.

imum output of 8.5 kV at 1.5 mA. The RF signals are applied by the drivers, which are synchronized with the powerline voltage so that the RF pulses appear near the powerline peaks as shown in Figure 2. The starting time and duration of each RF pulse is determined by the parameters of multivibrators in the drivers.

The two electrode sets are made of conductive paint on acrylic sheets of 0.5 mm thickness. The solid electrode of each set is painted on one side of a sheet while the finger electrodes of each set are painted on the other side. The two sheets are bent to fit into a cylindrical holder of 81 mm inside diameter.

When the voltages are applied, there is a stable distribution of ac corona sites along the finger electrodes at a spacing of about 100 μm. To test the charger, a metal-

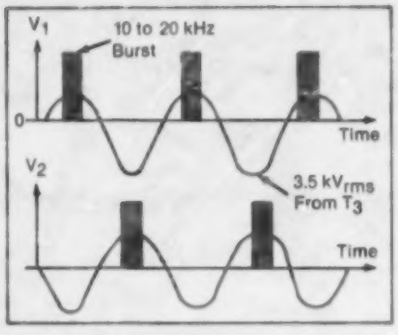


Figure 2. Voltages on the Finger Electrodes are shown here as a function of time for the circuit of Figure 1. With these polarities and timings, an object placed in the electrode cylinder would become positively charged.

ized glass sphere of 14.3 mm diameter was mounted on an insulating stalk at the center of the cylinder for about 5 s at a time. The sphere was then transferred to a faraday cup for the measurement of the charge.

The charge on the sphere was measured as a function of various combinations of RF and accelerating voltages and pulse timings. A maximum charge of 3.2 nC was observed with 5 ms RF bursts of 5.2 kV (peak to peak) positioned at 3.5 ms after the zero crossing of the accelerating voltage of 8.5 kV rms (center tapped).

This work was done by Won-Kyu Rhim, Daniel D. Elleman, Brian Makin, and William T. Simms of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 3 on the TSP Request Card. NPO-16523*

Calculating Directivities of Planar-Array Antenna Feeds

Radiation patterns are computed rapidly from expressions in closed form.

NASA's Jet Propulsion Laboratory, Pasadena, California

The design of planar-array antennas and antenna feeds is aided by a new approach to the calculation of array directivity. The technique takes into account polarizations, asymmetries in element patterns, nonuniform element spacings, and arbitrary excitations. It gives numerical results faster than previous integration methods, and the results agree with those obtained by the older methods.

The technique applies to a planar array of M identical radiating elements with identical polarization states at arbitrary locations and excited with feeds at arbitrary amplitudes and phases (see figure). The array is assumed to radiate only into the upper half space $z > 0$. The directivity D of the array in the direction θ,ϕ is defined by

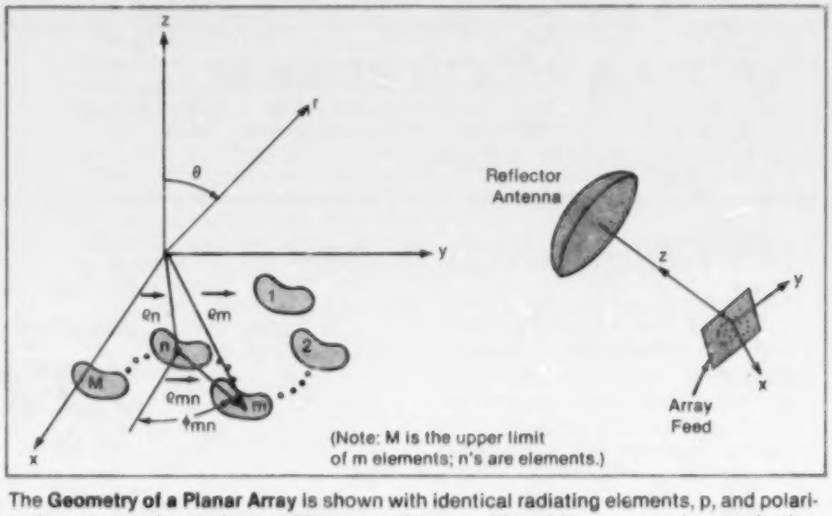
$$D(\theta,\phi) = \frac{4\pi I(\theta,\phi)}{P}$$

where θ and ϕ represent the polar and azimuthal angles, P = the total radiated power, and $I(\theta,\phi)$ = the radiation intensity in that direction.

The calculation of P requires the integration of $I(\theta,\phi)$ over all solid angles. Until now, the practice has been to evaluate the integrals numerically. This is a tedious and time-consuming process. In the new approach, the process is speeded up by taking advantage of the fact that the integrals are equivalent to closed-form expressions containing Bessel, gamma, and Lommel functions. These functions can be evaluated directly by table lookup or by series approximations.

The new technique was applied to some special cases including arrays with large spacings, elements with symmetric patterns, and linear arrays of isotropic elements. The technique was used to calculate the directivities of circularly polarized seven- and nine-element cluster feeds used in multiple-beam designs. It was also applied to a 25-element array feed for a satellite antenna to produce a beam covering the eastern time zone of the United States. Comparisons were made with the results obtained from direct numerical integration and other, less general formulations. Excellent agreement was obtained in all cases.

This work was done by Yahya Rahmat-Samii and Shung-Wu Lee of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 10 on the TSP Request Card. NPO-16505*



The Geometry of a Planar Array is shown with identical radiating elements, p, and polarization states located at arbitrary positions with arbitrary, complex excitation coefficients.

Reliable One-Shot Separation of Connectors

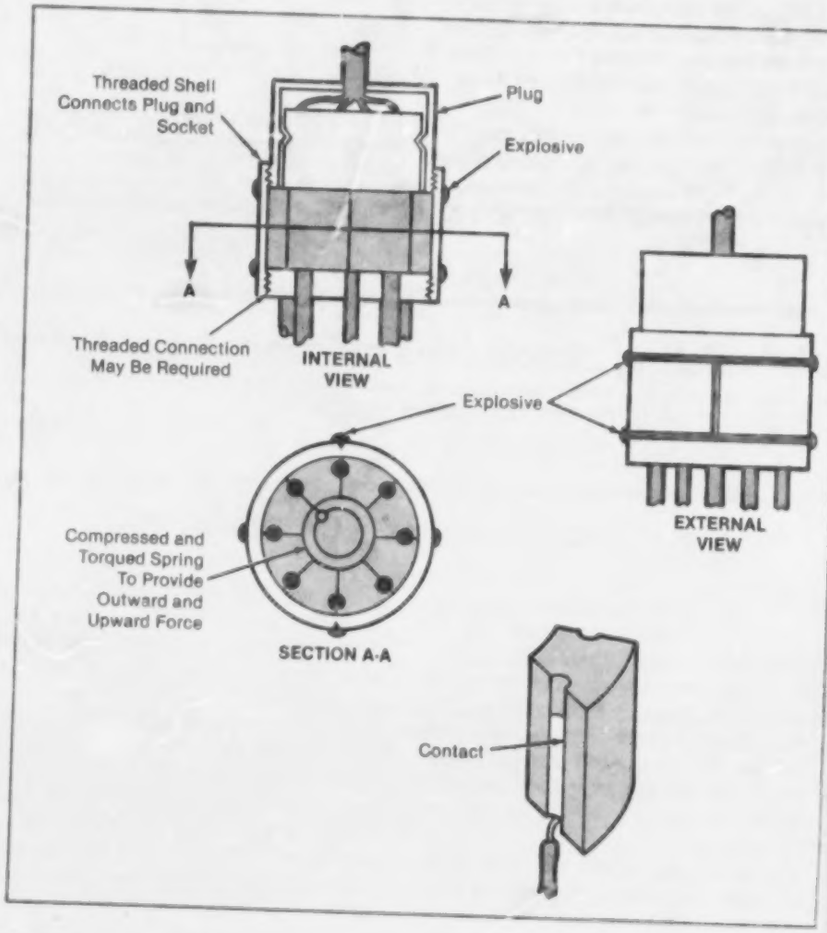
A mild explosion breaks the connection.

Lyndon B. Johnson Space Center, Houston, Texas

A concept for separating electrical connectors by remote control is simple and reliable. Suitable for one-time, irreversible separations, the method uses a weak explosion to destroy one member of the connector.

The connector consists of a threaded plug and socket (see figure) around which a tape of Superzip (or equivalent) explosive is wrapped. When the explosive is fired by an electrical signal, it fractures the socket case and releases its segmented connector elements, which are pushed upward and outward by a compressed and torqued spring. The plug is thereby freed. The concept is adaptable to fluid connections as well as to electrical ones.

This work was done by William R. Holmberg of McDonnell Douglas Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20839



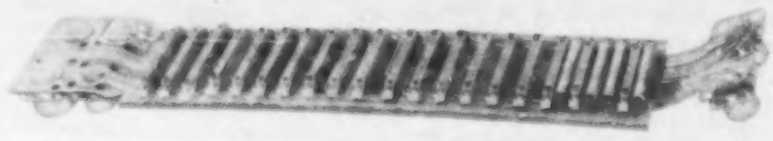
A Connector Wrapped With Explosive opens upon detonation. The fractured socket elements may be tethered to prevent them from flying away and forming debris.

Flex Circuitry for Confined Spaces

Circuits are preassembled, then bent into confined spaces.

Lyndon B. Johnson Space Center, Houston, Texas

To facilitate the installation of electronic equipment in confined spaces, circuitry is preassembled on flexible wiring. Mother boards, large bypass capacitors, and interface connectors are mounted on the flexible wiring and tested before installation. Originally developed for use on the Space Shuttle, the flexible circuits eliminate the need for in-place hardwiring and allow smaller enclosures to be used.



Flexible Wiring contains nine layers of copper conductors, on which are installed circuit-board connectors, cable connectors, and large capacitors. This type of wiring allows installation of complex circuitry in confined spaces.

The base for the flexible wiring is a polyimide, in which copper-foil conductors are embedded in nine layers. Once assembled (see figure), the flexible circuit is visually inspected and tested for dielectric strength, insulation resistance, and continuity. When testing is completed, all exposed connections are coated for electrical and mechanical protection.

This work was done by Joel B. FitzPatrick and Larry C. Maier of Simmonds Precision for **Johnson Space Center.** *For further information, Circle 23 on the TSP Request Card.*
MSC-20773

Improved Solar-Cell Tunnel Junction

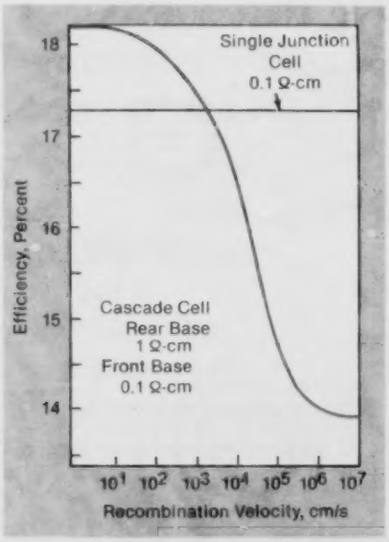
Cell efficiency would be increased.

NASA's Jet Propulsion Laboratory, Pasadena, California

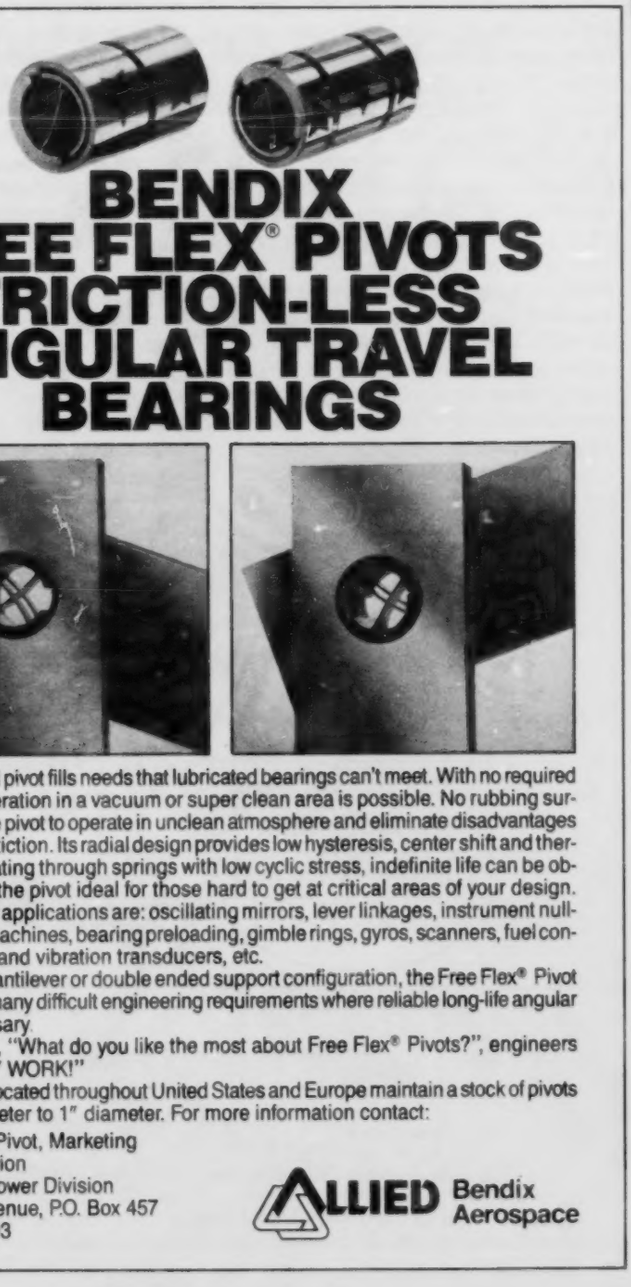
The efficiency of multiple-junction silicon solar cells may be increased by the inclusion of p^+/n^+ tunnel junctions of highly doped GaP between the component cells. The relatively low recombination velocity at the GaP junction is the principal reason for recommending this material.

Recombination losses reduce the efficiency of multiple-junction cells with silicon p^+/n^+ tunnel junctions, where the interface recombination velocity is about 10^6 cm/s. In a GaP p^+/n^+ junction, however, the recombination velocity is expected to be lower by a factor of 10^3 or more (see figure).

GaP offers other advantages. Its lattice match with Si is good, so defects usually associated with lattice mismatches between layers are avoided. With a band gap of 2.3 eV, the GaP layers form a high barrier to minority carriers diffusing to the p^+/n^+ interface, resulting in a nearly zero theoretical tunneling probability for such carriers. The relatively wide band gap also helps to



The **Efficiency of a Typical Cascade Solar Cell,** as estimated theoretically, is compared to that of a typical single-junction cell. If the recombination velocity can be made low enough, the cascade cell will be more efficient.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increase efficiency by reducing optical losses.

This work was done by Taher Daud and Akaram Kachare of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 15 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 21]. Refer to NPO-16526

Advanced IPV Nickel/Hydrogen Cell

Expansion and contraction of the electrode stack are accommodated to increase cycle life.

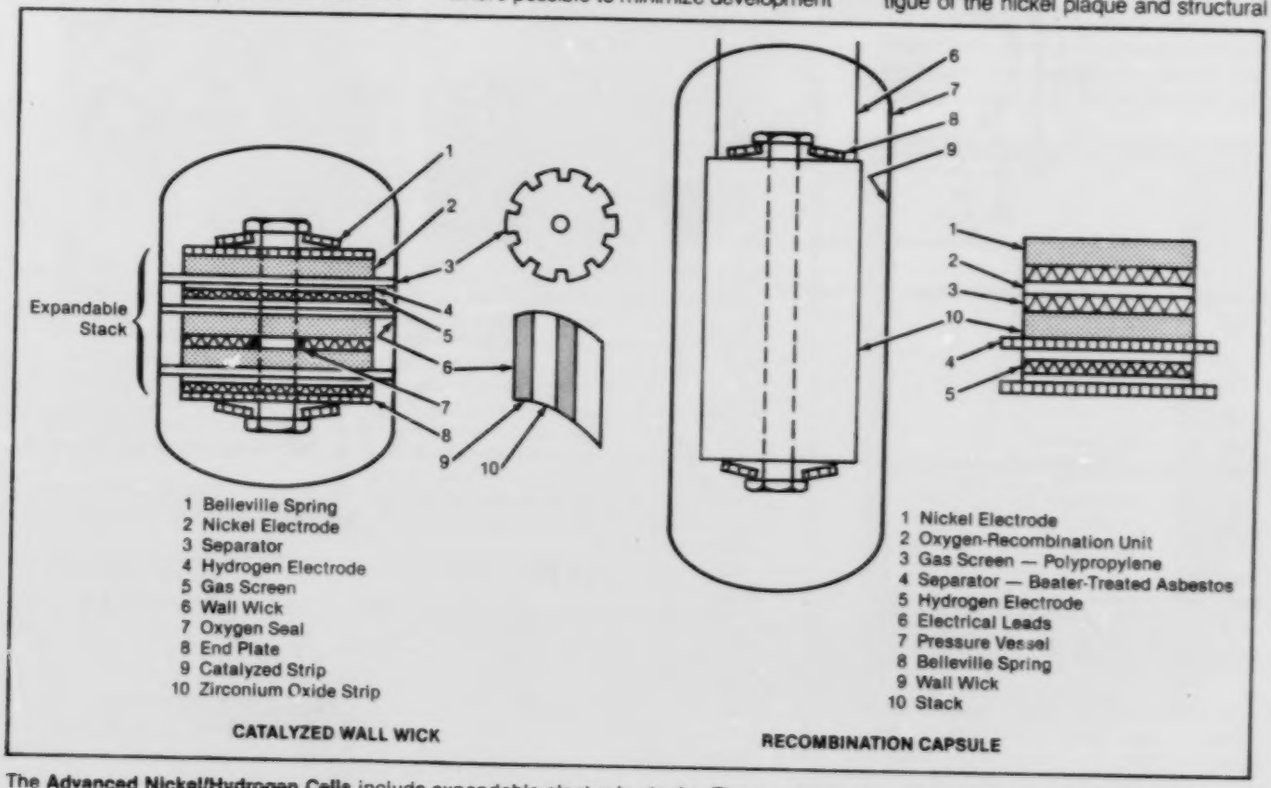
Lewis Research Center, Cleveland, Ohio

Advanced designs for individual-pressure-vessel nickel/hydrogen cells have been conceived that should improve the cycle life at deep depths-of-discharge. Three features of the designs that are new and not incorporated in either of the contemporary cells are (1) the use of alternate methods of oxygen recombination, (2) the use of serrated-edge separators to facilitate the movement of gas within the cell while still maintaining required physical contact with the wall wick, and (3) the use of an expandable stack to accommodate some of the nickel electrode expansion. The designs also consider electrolyte volume requirements over the life of the cells and are fully compatible with contemporary designs.

As part of an overall effort to advance the technology of nickel/hydrogen batteries for possible use in an energy-storage system, in low Earth orbit (LEO), improved advanced designs for individual-pressure-vessel (IPV) cells have been conceived. Contemporary IPV nickel/hydrogen cell designs and the results of cycle-life tests conducted in-house and by others were reviewed to identify areas where improvement could result in a longer cycle life. A component-improvement effort directed toward the physical properties of each of the individual components was initiated, and improvements were factored into the cell. Design philosophies have been developed related to oxygen- and electrolyte-management requirements. Existing technology was utilized where possible to minimize development cost and time.

The contemporary-design cells are adequate for the geosynchronous-orbit (GEO) applications, where not many cycles are required over the life of the storage system. However, for the demanding LEO applications, the current cycle life at deep depths-of-discharge (2,000 to 8,000 cycles) is not acceptable. Some investigators report that this limited cycle life is mainly due to degradation of the nickel electrode. However, there are also indications that other modifications to the contemporary designs should result in an improved cycle life.

Some possible causes of degradation are (a) density changes of the active material during cycling that could cause fatigue of the nickel plaque and structural



The Advanced Nickel/Hydrogen Cells include expandable electrode stacks. The two types shown here differ in the method of oxygen recombination.

damage to itself resulting in capacity loss, and (b) active material could flake or extrude from the electrode causing a loss of capacity and possible shorting of the cell. The extrusion of active material may also cause the channeling of oxygen generated during charge. This could lead to "popping" caused by large concentrations of oxygen reacting with hydrogen at the hydrogen electrode that could damage the electrode.

Blistering of the nickel electrode during cycling could cause capacity loss. Changes in pore distribution and electrode surface area can also result from active material expansion and contraction, which could affect electrolyte distribution and performance. It has been reported that the nickel electrode expands significantly during cycling. This could cause compression of the separators, drying of the stack, rupture of the polysulfone core, and cell failure. This failure mode can be eliminated by modifying the cell design to accommodate expansion.

Two different but similar advanced-design IPV nickel/hydrogen cells have been conceived. They are illustrated in the figure. One is referred to as the catalyzed wall wick; and the other, as the recombination capsule design. They differ only in the method of oxygen recombination. Initially the nickel electrodes, hydrogen electrodes, gas screens, pressure vessel, and potassium hydroxide electrolyte concentration will be identical to the ones used in the state-of-the-art.

The three features of the advanced designs that are new and not incorporated but fully compatible in either of the contemporary cells are (1) the use of alternate methods of oxygen recombination, (2) the use of serrated-edge separators, and (3) the use of an expandable stack. The designs also consider electrolyte volume requirements over the life of the cells and are fully compatible with state-of-the-art designs. Cells of these design variations should improve performance, life, and usable energy leading to lighter storage devices for low Earth-orbit applications for commercial or government applications.

This work was done by John J. Smithrick, Michelle A. Manzo, Olga Gonzalez-Sanabria and Daniel G. Soltis of **Lewis Research Center.** *Further information may be found in NASA TM-83643 [N84-23025/NSP], "Advanced Designs for IPV Nickel Hydrogen Cells" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 21]. Refer to LEW-13969.

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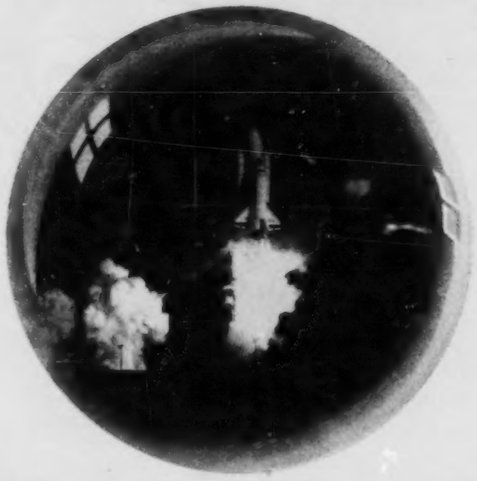

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68 Single-Event Upsets Caused by High-Energy Protons
69 Hyperspectral Infrared Images of Terrain

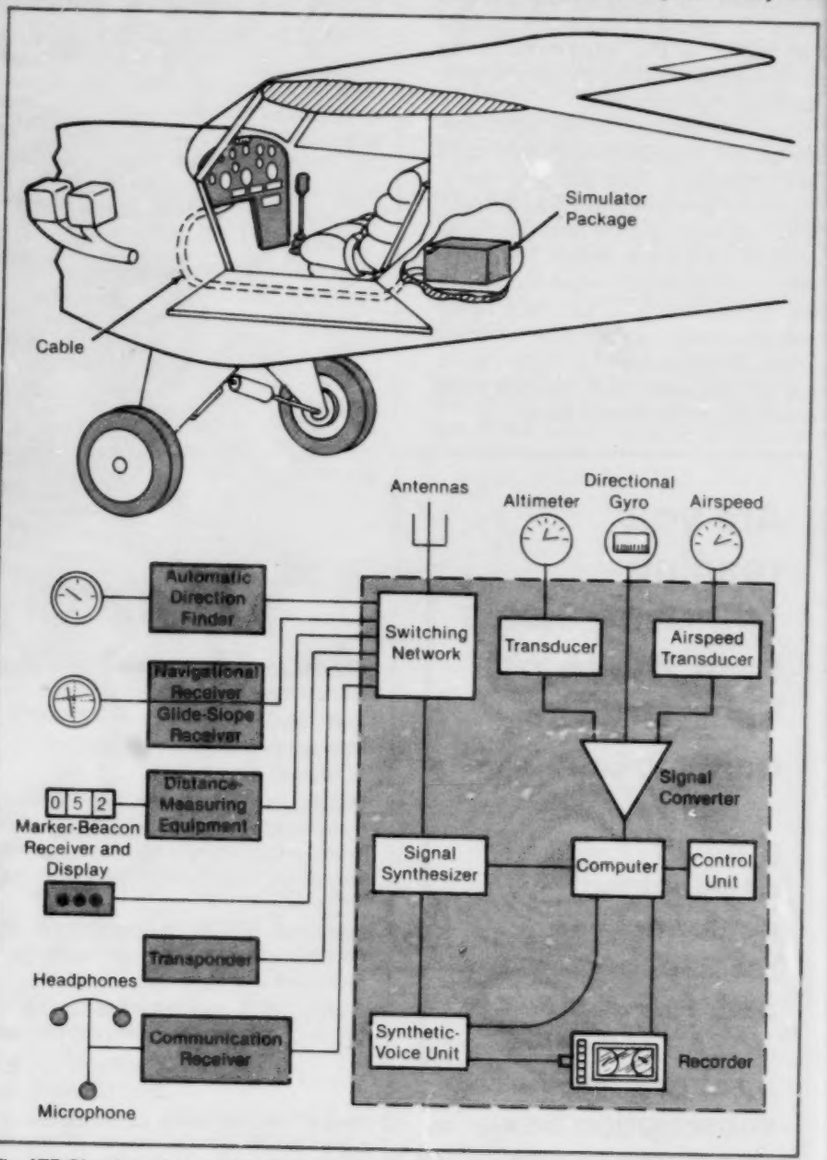
In-Flight Simulator for IFR Training

A computer-controlled unit feeds navigation signals to airplane instruments.

John F. Kennedy Space Center, Florida

An electronic training system allows students to learn to fly according to instrument flight rules (IFR) in uncrowded airspace. The new system (see figure) is a self-contained IFR simulator that is carried aboard the training plane. It generates signals and commands for the standard instruments on the airplane, including a navigational receiver, distance-measuring equipment, an automatic direction finder, a marker-beacon receiver, an altimeter, an airspeed indicator, and a heading indicator.

A training session usually begins on the ground at a remote airport. The student and instructor load a simulation program and data from a tape cassette into a microcomputer in the system. They take



The IFR Simulator is contained in a compact, lightweight package on a training airplane. The simulator provides simulated inputs to standard navigation and instruments. A switching network routes simulated signals to the proper equipment and disconnects the equipment temporarily from antennas.

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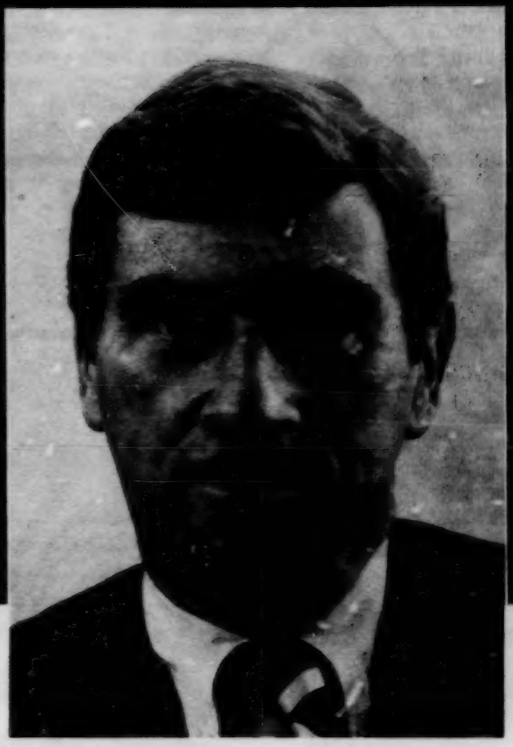

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out the navigation and approach charts for the simulation. They take off and proceed to the altitude of the simulated airport at 500 to 1,000 ft. (150 to 300 m) above the local terrain where the simulation begins.

Under the control of the microcomputer, a voice synthesizer clears the plane for the simulated takeoff and directs the student to maintain a designated heading. The student then proceeds to fly a predetermined course. Meanwhile, the microcomputer continually provides updating signals appropriate to the changing simulated position to the navigation instruments.

The voice synthesizer issues messages along the way. For example, it tells the student to change frequency when the plane enters another simulated traffic-control area. If the pilot strays from the preplanned course, the synthesizer delivers an error message, just as a real air-traffic controller would. The training session ends when the plane lands at the simulated airport; a simulated missed-approach procedure can be included in the landing.

The system can be stopped during a training session so that the instructor can explain an error. Voice commands can be stopped while position integration continues so that the student can practice a procedure such as maintaining a holding pattern.

A key component of the system is a signal synthesizer, which generates a variety of signals like those that would normally be received by the navigational receivers. During a simulation, the microcomputer disconnects the navigational receivers from their antennas so that they can receive the simulated input signals along the simulated route.

This work was done by Loyd C. Parker of **Kennedy Space Center.** *For further information, Circle 46 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,490,117). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Kennedy Space Center [see page 21]. Refer to KSC-11218.

Timed Multiple-Laser Array

Pulse power, frequency, and shape would be variable and combined to suit particular applications.

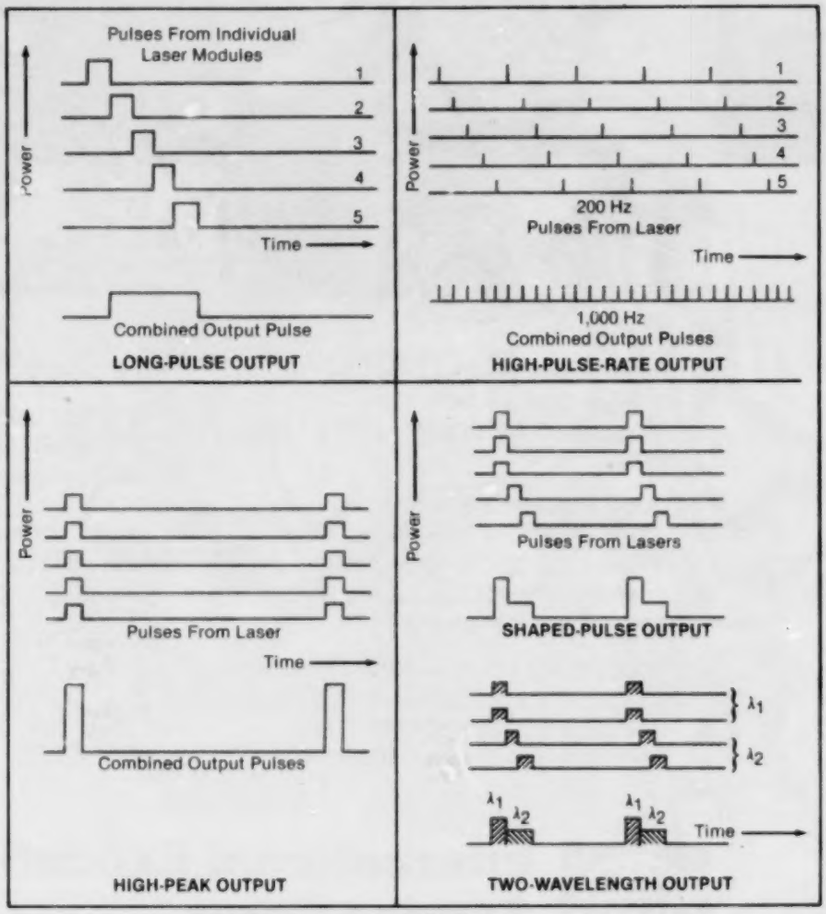
NASA's Jet Propulsion Laboratory, Pasadena, California

A versatile laser system would combine high power with high efficiency, long life, and low cost. The proposed system would consist of an array of excimer lasers fired under microcomputer control. When fired in unison, the array would produce a high-power pulse at a higher efficiency than would otherwise be possible. When fired in sequence, the array would produce pulses at a high rate without unduly stressing components and shortening their lives (see figure).

The array would be made of several modules, each module being an inert gas/halogen laser excited by an electrical pulse. Such an array would have a variety of important uses. Metal welding by laser, for example, requires microsecond pulses to melt the material at joints. A single excimer laser cannot produce such a long pulse; the maximum pulse width would be about 200 nanoseconds. However, 10 excimer lasers fired in sequence, without pause, in 100-nanosecond pulses would produce an effective pulse length of 1 microsecond.

Alternatively, such an array could be operated with intervals between pulses to produce a series of energy bursts at high average power. Ten lasers operating at 100 hertz in a synchronized firing sequence would produce an output at 1 kilohertz. The array could be cheaper and more efficient than a single laser generating the same average power at the same high pulse rate.

Such other applications as solar-cell annealing require a single high-energy pulse of ultraviolet light for a short duration. For example, a solar cell 100 square centi-



Pulses From the Individual Lasers in an array can be combined in various ways to suit a particular application. Examples illustrated here are for a five-laser array. A microcomputer would control the electrical signals that fire the lasers.

meters in area requires a 150-joule beam, 10 by 10 centimeters in cross section, for 50 nanoseconds for annealing in a single pulse. Designing a single laser for this application would be a formidable engineering challenge, but 10 lasers simultaneously producing 15 joules could do the job.

The firing of the lasers in the array could be phased to shape the output pulse. For example, firing of 6 lasers in a 10-laser array could be followed immediately by firing of the remaining 4, producing a fast-rising, slowly falling output pulse. This kind of pulsing would be useful in cutting and drilling.

An excimer array could also be used to enhance the operation of another type of laser. For example, carbon dioxide lasers are powerful and efficient, but are not effective in cutting metals that absorb infrared radiation only slightly. However, if an excimer array were fired so that its pulses would immediately precede those from a carbon dioxide laser, it would melt the metal surface and reduce its infrared reflectivity so that the carbon dioxide laser could then cut more effectively.

An important advantage of a laser array is that if one of the lasers is not functioning, the system can continue to operate, albeit at reduced capacity. Moreover, there is a longer interval between part replacement and maintenance than for a single laser of equal capacity because components are operated more conservatively.

This work was done by James B. Laudenslager and Thomas J. Pacala of Caltech, for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 12 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 21]. Refer to NPO-16433.

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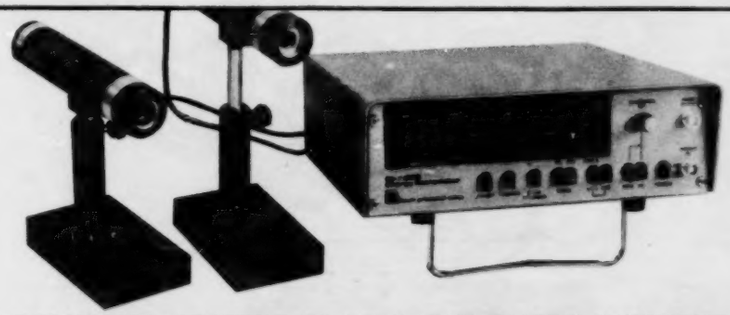

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Rjp-736	Flat	20.0cm²	$1x10^{-4}$	$1x10^{3}$W/cm²	±3% (0.4-1μm); +3%, −9% (0.35-11 μm)
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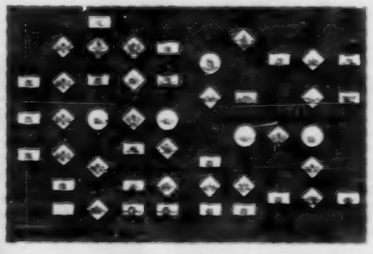

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CIRCLE NO. 302

Detector Arrays With Image-Plane Processing

Image detection and edge processing are merged on the same VLSI chip.

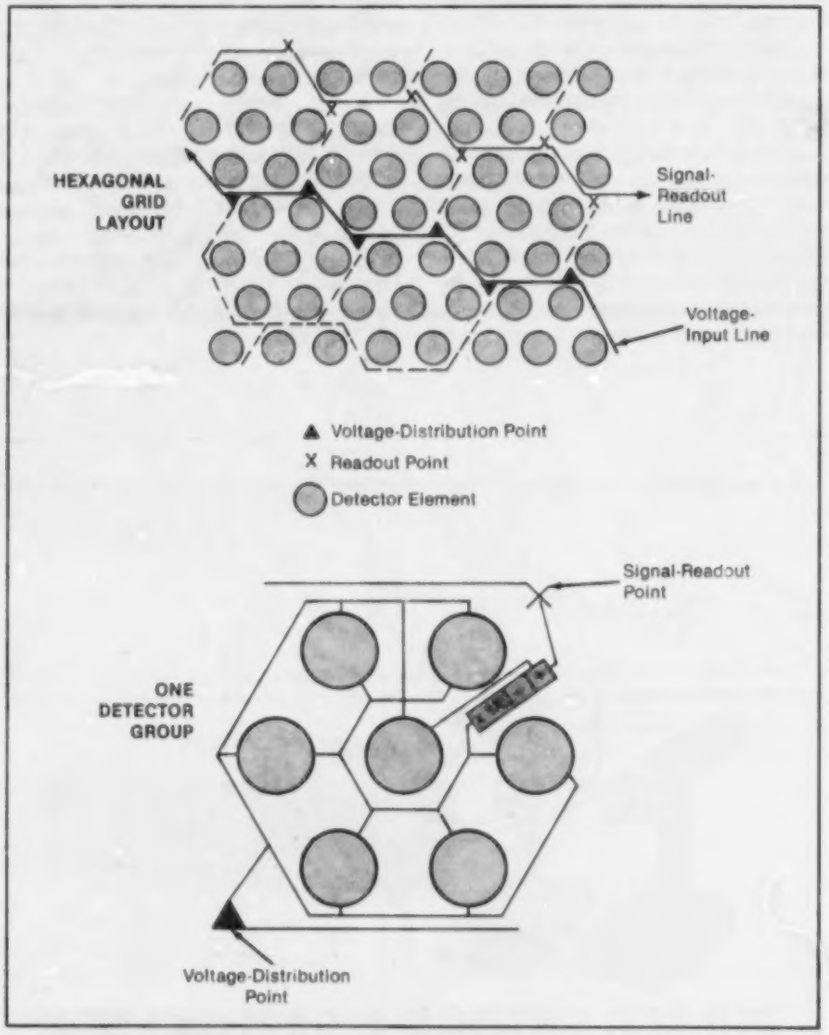
Langley Research Center, Hampton, Virginia

Previous approaches to machine vision have concentrated on special-purpose computational hardware, including focal-plane processor chip technologies. In most cases, detection and processing are considered as distinct submodules. In a newly proposed device, edge processing of picture elements is incorporated on the same VLSI (Very-Large-Scale Integration) chip as that of the image-detection elements.

The concept combines relatively large detector elements with small processor elements as VLSI chip features and can have many specific embodiments. Previous VLSI and VHSIC (Very-High-Speed Integrated Circuit) processor-chip designs have generally sought to diminish all individual features on the chip to the smallest size possible and have not merged detection with processing. The new device concept retains relatively large detector element sizes (perhaps 10 to 100 μm or larger in diameter) with processing-electronics components of much smaller size (2 μm or less), filling in gaps left between the detector-element active areas.

The specific design concept shown schematically in the figure is for realizing a difference-of-Gaussian (DOG) operator in a detector/processor array for use in machine-vision edge-enhancement and edge-detection applications. A sequential approach to input voltages and readout is shown, but a parallel approach is also possible if readout and voltage distribution points feed through to the base of the substrate material.

The principal functional components



The **Detector-Array Device** would help to perform the difference-of-Gaussian operation for use in machine-vision edge enhancement and edge detection.

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2	General Motors	26	AT&T Technologies
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6	Texaco	30	Eastman Kodak
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for creating a DOG operator are the inversion and attenuation of the signals from the six detector elements surrounding the central element and the summation of various signal contributions for readout. The attenuation factor is about one-sixth for the six surrounding elements. A lens-blur function smooths the detector-element spatial response to obtain approximately a DOG-group response function and minimizes the effect of gaps between adjacent detector elements.

This work was done by Daniel J. Jobson of **Langley Research Center.** *Further information may be found in NASA TM-85809 [N84-25927], "Edge Analyzing of Center/Surround Response Functions in Cybernetic Vision" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 21]. Refer to LAR-13391.

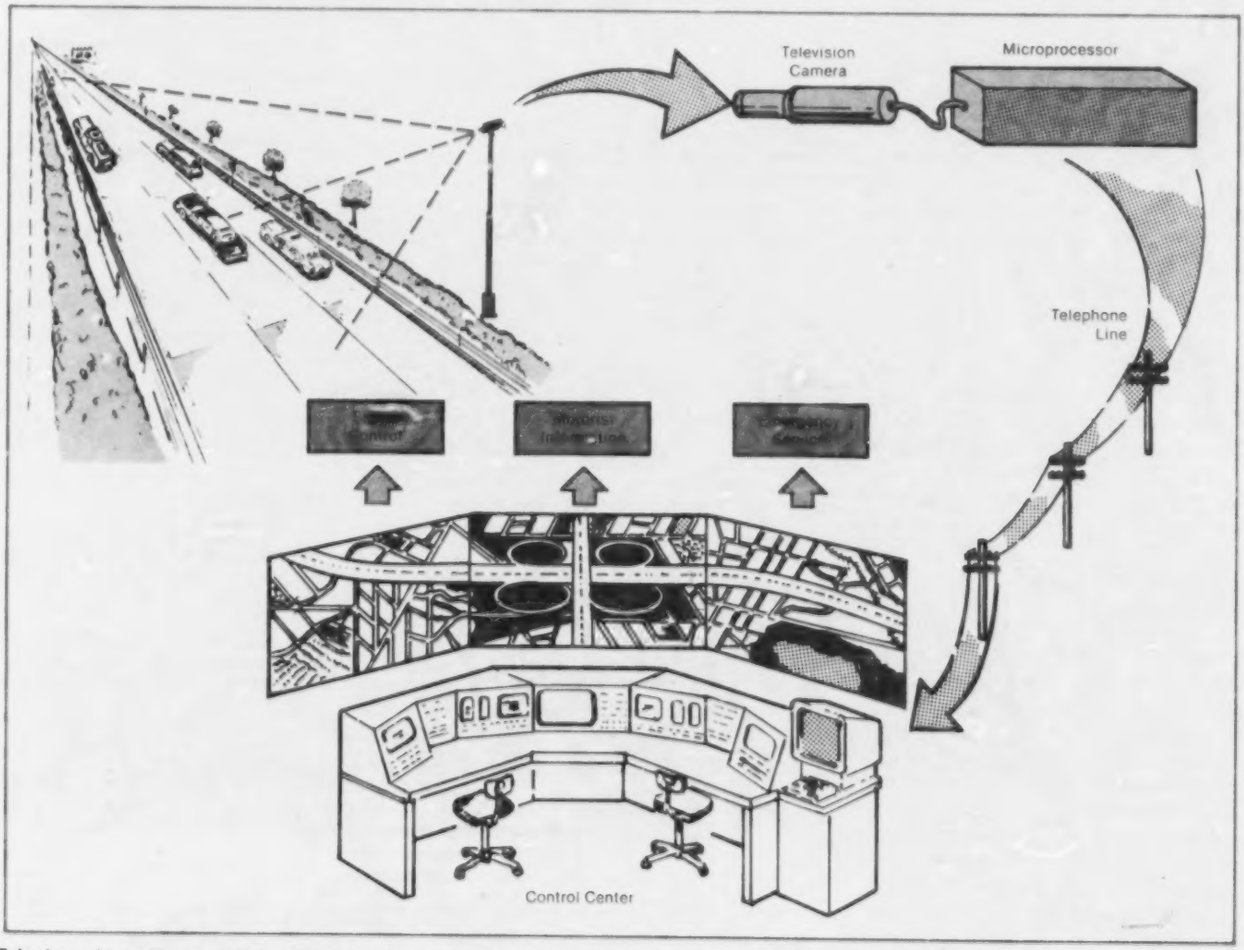
Economical Video Monitoring of Traffic

Data compression allows video signals to be transmitted economically on telephone circuits.

NASA's Jet Propulsion Laboratory, Pasadena, California

A video system with television cameras positioned at critical points on highways allows traffic controllers to determine visually, almost immediately, the exact cause of a traffic-flow disruption; e.g., accidents, breakdowns, or spills, almost immediately. The controllers can then dispatch appropriate emergency services and alert motorists to minimize traffic backups.

The system (see figure) incorporates data compression so that 9,600-baud telephone lines can be used to carry video signals. Such costly wideband communication links as coaxial cable, light guide, or microwave transmission are not needed. The new system produces pictures of adequate quality and at sufficiently high rates so that problems on roads are readily noticed and identified. An analysis has shown that the costs of



Telephone Lines Transmit Television Signals to a remote traffic-control center. The lines also carry command signals from the center to the TV camera and compressor at the highway site.

operating this system could be substantially less than for a system with wideband transmission, even with the inclusion of data-compression equipment for the narrow-band system.

A field test of a prototype system was conducted by NASA's Jet Propulsion Laboratory and a private organization in cooperation with the Maryland Department of Transportation (MDOT). A television camera with remote pan, tilt, and zoom controls was erected at the intersection of Interstate Highway 695 (the Baltimore Beltway) and Interstate 70. Video images were transmitted via telephone lines to MDOT offices in Glen Burnie, about 10 miles (16 kilometers) away.

The system uses data-compression and error-suppression techniques similar to those used to transmit television images from interplanetary spacecraft to Earth. One of the most attractive features of these techniques for traffic applications is that an operator can vary the compression and the corresponding picture quality and frame rate at the remote control center.

At the highway site, the system converts the camera image into a 256-by-256 array of 8-bit numbers. It subjects this numerical representation of the picture to a series of parallel transformations designed to alter its statistical properties and suppresses enough data to produce frames at the rate designated by the operator. The telephone channel carries the coded picture to the receiving subsystem at the control center. There, the process used to compress the picture for transmission is reversed, and the original picture is reconstructed as closely as possible.

Using the remote TV camera controls, the operator scans the field of view at a high frame rate to locate problems on the highway. Once a problem is spotted, the operator reduces the frame rate and thereby improves the image quality to identify the type of problem. The transmission time for an uncompressed image at full resolution is 51 seconds. With compression, useful transmission times range from about 0.3 seconds per frame for vehicle counting and speed detection to 7 seconds per frame for problem identification.

This work was done by Bradford C. Houser, Garrett Paine, Louis D. Rubenstein, and O. Bruce Parham, Jr., of Caltech for **NASA's Jet Propulsion Laboratory** *and William Graves of Dalmo Victor, Textron, and Cedric Bradley of MDOT. For further information, Circle 43 on the TSP Request Card.*
NPO-16473

Integrated-Circuit Active Digital Filter

Pipeline architecture with parallel multipliers and adders speeds calculation of weighted sums.

NASA's Jet Propulsion Laboratory, Pasadena, California

New digital integrated-circuit chips with pipeline architecture rapidly move 35 × 35 two-dimensional convolutions. There is a need for such circuits in image enhancement, data filtering, correlation, pattern extraction, and synthetic-aperture-radar image processing, all of which require repeated calculations of weighted sums of values from images or two-dimensional arrays of data.

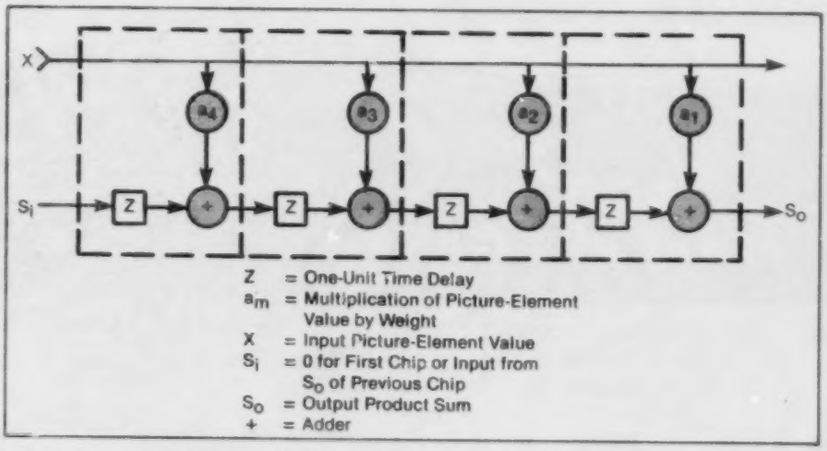
Q set of chips (each containing a one-by-five set of multiplier/adders) can serve as a fast digital filter when attached to a host computer. In an m × n digital filter, for example, processing an image of 1,000 × 1,000 elements, each element value is replaced by a weighted sum of the values of an m × n rectangular subarray of elements centered on the given element. For this new hardware, each value and each weight are fetched from memory only once. First the m × n array of weights is loaded into the filter, where it remains throughout the calculation. Then the image data are shifted into and through the filter as the filtered element values are calculated. A general-purpose computer would perform the same calculation much more slowly: Each element value would be fetched from memory m × n times, once for each element of the weighting subarray in which it appears.

Each chip contains five multiplier/adders executed in metal-oxide semiconductor circuitry. A delay-adder modular design (see figure) provides a "bucket-brigade" transfer of the accumulated product sum, thereby saving multiple accesses to the host computer memory. As many of these chips as necessary can be cascaded together to form an array containing m × n multipliers. Delay lines are used to retain data between use in succeeding rows of the filter. For example, one row of a 35 × 35 filter would require seven chips. The chips for one such row will fit in one 68-pin flatpack 3.5 by 1.5 in. (90 by 40 mm) in dimension.

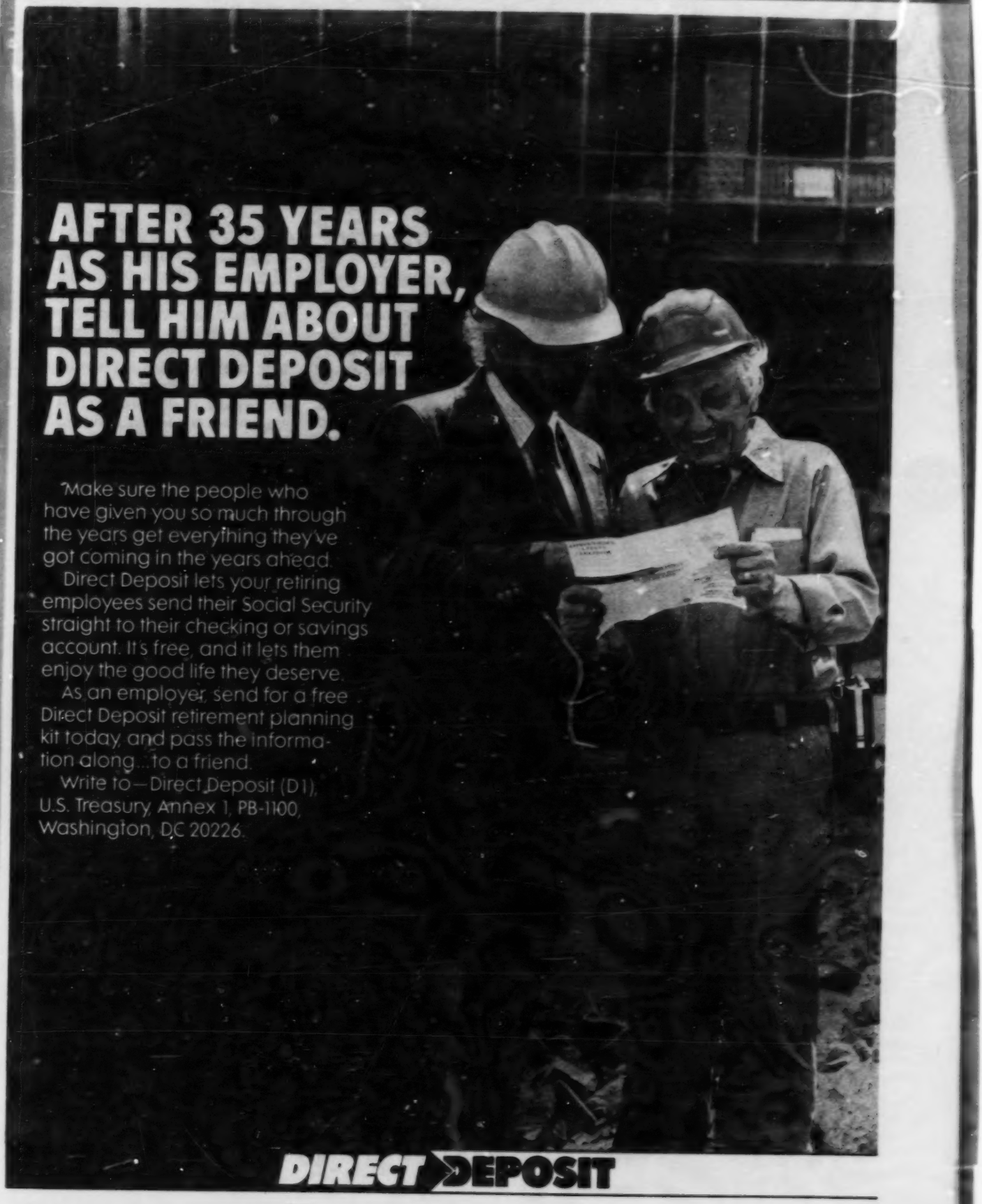
Both the data and the sums move through the chip in a pipelined manner. Each of the 1,225 multiplications and additions taking place at any given moment contributes to a different weighted sum.

This work was done by Robert Nathan of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 37 on the TSP Request Card.*

Title to this invention has been waived, under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the California Institute of Technology. For further information regarding nonexclusive or exclusive licensing, contact Edward O. Ansell, Director of Patents and Licensing, 307 Keith Spalding Building, Pasadena, CA 91125. Refer to NPO-16020.



Picture-Element Values and Partial Sums flow through delay-adder modules like this one. After each cycle or time unit of the calculation, each value in the filter moves one position to the right.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Intermediate-Frequency-to-Video-Band Converter

Analog and digital circuits are combined to frequency-convert from intermediate frequencies directly to video-band frequencies to meet stringent requirements.

NASA's Jet Propulsion Laboratory, Pasadena, California

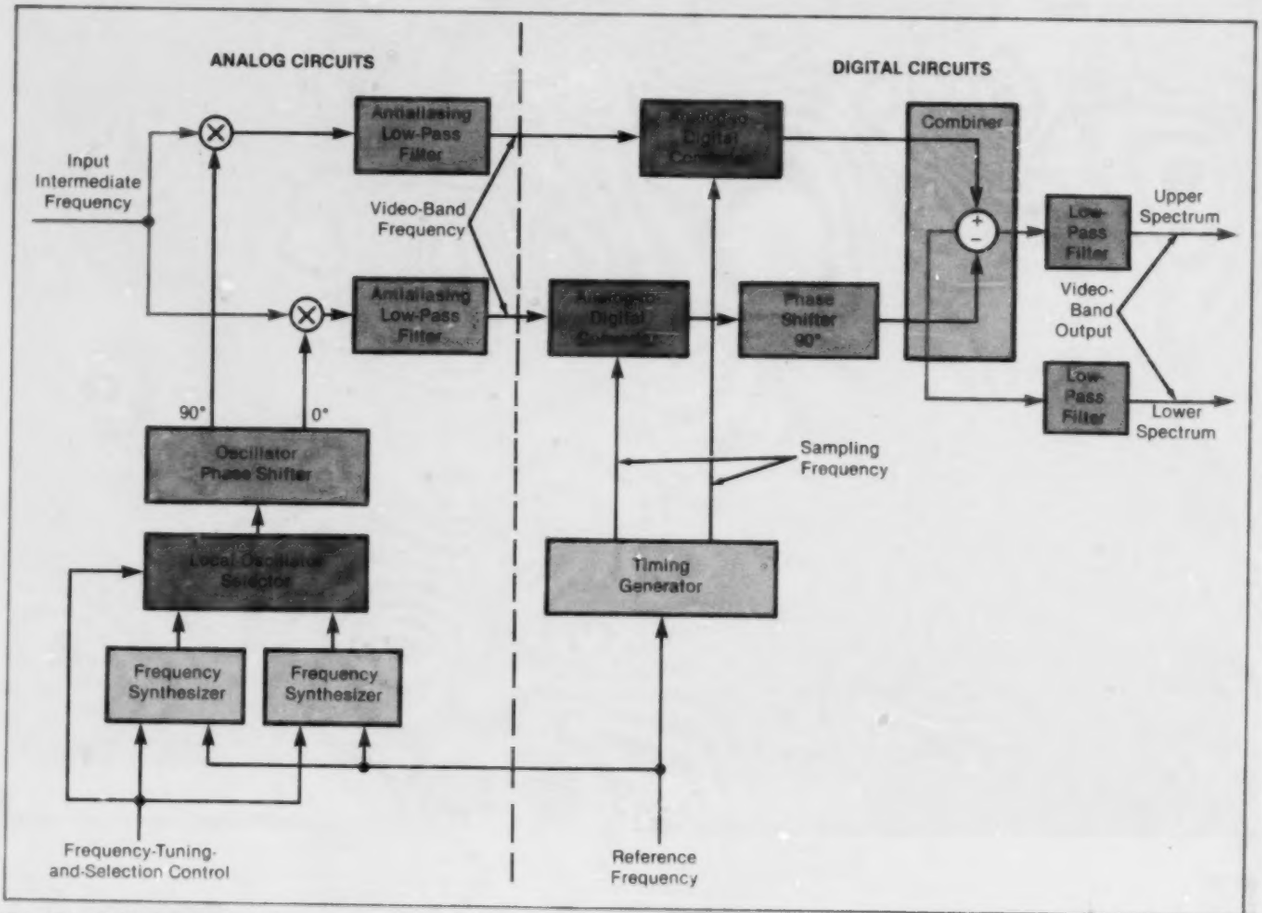
A hybrid analog-to-digital frequency downconverter (see figure) directly converts high intermediate frequencies (IF's) of the receiver directly to video-band frequencies (VF's) with features of high image-band rejection (>34 dB) and phase variations less than peak (about the average phase response) across 80 percent of the passband. The downconversion from the IF's to near-zero-frequency video-band output frequencies, with good adjacent image-band rejection, is achieved by use of the phase cancellation technique that has been applied in single-sideband rejection of modulated radio frequencies.

Downconversion to VF to near-zero frequency must overcome the problem of adjacent band signals and noise foldover into the desired passband. The desired passband can be either the upper or the lower spectrum immediately around the local-oscillator frequency, which can be set anywhere within the IF range. This conversion method (see figure) allows downconverting of any bandwidth-limited segment of the entire IF band without degrading the received signal-to-noise ratio.

As shown in the figure, two quadrature signals from the local oscillator are mixed with two IF input signals and downconverted to video-band near-zero frequency. These video-band signals are frequency-band limited by antialiasing low-pass filters (LPF's) prior to input to the digital circuits. These LPF's prevent unwanted interference signals (aliasing), generated in the digitization process, from appearing in the desired video passband.

The digital circuits perform the remaining function of phase shifting all frequencies by 90°, from one downconverted mixer output, combining these shifted frequencies with the other mixer output frequencies, and finally low-pass filtering after digitizing the analog input signals by the analog-to-digital converters. The 90° phase shifting over the range of the video frequencies and the final low-pass filtering were achieved better with digital circuits to meet the stringent requirements of good image-band rejection and low phase variation within the passband.

Either the upper or the lower spectrum of the IF band about the local-oscillator frequency can be selected with equal band rejection of the other spectrum, depending upon the polarity of the com-



This IF-to-Video-Band Converter operates on the principle of signal-band cancellation in phase-quadrature circuits. It can downconvert intermediate frequencies directly to video-band frequencies to near-zero frequency with good iamge-band rejection and low phase variation within the passband.

bined output. Thus the downconversion of any band-limited segment of the IF band to video band, with the same image-band rejection and good phase-variation limitation, is available over a wide band of IF input signals. This is limited only by the frequency range of the IF and local oscillators and the capability of providing two quadrature signals from the local oscillator over the frequency range.

This work was done by North C. Ham, Victor M. Chavez, Victor S. Chen, and Takeshi Sato of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 40 on the TSP Request Card.*

NPO-16214

Hardware/Software Expansion of Display Terminal and CPU

An IBM PC coupling is used to expand the capabilities of an expensive special-purpose system.

Langley Research Center, Hampton, Virginia

The capabilities of a Tektronix digital processing oscilloscope (DPO) system used to process data from a molecular beam/mass spectrometer system were significantly expanded at low cost when the oscilloscope was coupled to an IBM personal computer (PC). The IBM PC (832K, 8-bit byte memory) was interfaced to the Tektronix CP1151 computer (32K, 16-bit word memory) through the teletype port of the Tektronix 4010-1 computer display terminal. An electronic interface was built to provide isolation, level shifting, and signal inversion between the IBM PC RS-232 port and the 4010-1 terminal teletype port. Modifications to the 4010-1 terminal were made to increase the teletype rate from 110 to 9,600 baud. Software for both computers was developed to give control of the DPO system to the IBM PC and to provide data/program file exchange between the two computers.

Three modes of operation are possible: standard operation of the DPO system, using the 4010-1 display terminal as the keyboard and control input; standard operation of the IBM PC; and linked operation, using the IBM PC and its keyboard as the control input to the DPO system. During linked operation, the IBM PC can be used simply as a remote display terminal for the DPO system, or the expansion capabilities of the IBM PC can be added to the DPO system.

The coupled system is a relatively inexpensive memory expansion of the DPO, which greatly exceeds that currently available from Tektronix. All software and hardware available for the IBM PC can be utilized with the DPO as needed. The IBM PC can be connected through a specially-designed transistor/transistor-logic-to-teletype isolator/coupler interface to the Tektronix CP1151 computer teletype input/output. This eliminates the need for the 4010-1 display terminal (provided that a baud rate X16 clock is included). The increased limit for the number of mass-spectrometer data files that can be analyzed at one time with the coupled system offers a new level of flexibility. In general, this coupling demonstrates the utilization of low-cost microcomputer hardware and software to expand the capabilities of expensive special-purpose computer systems.

This work was done by Billy R. Adams of Kentron International, Inc., for **Langley Research Center.** *For further information, Circle 84 on the TSP Request Card.*

LAR-13350

Pseudolog Digital-to-Analog Converter

The sensitivity decreases by 10 at the beginning of each input decade.

Lewis Research Center, Cleveland, Ohio

A method has been conceived to convert binary-coded data to a suitable linear form for strip-chart recording. As an example of the use of this method, the pressure level of high-vacuum facilities is typically monitored by means of a Bayard-Alpert ionization tube coupled with appropriate readout electronics. The typical vacuum range for these ionization gages is from 10^{-3} torr down to 10^{-10} torr (10^{-1} to 10^{-8} Pa). For vacuum-facility monitoring purposes, a strip-chart record of facility pressure as a function of time is frequently desired. Thus, most commercially available ioni-

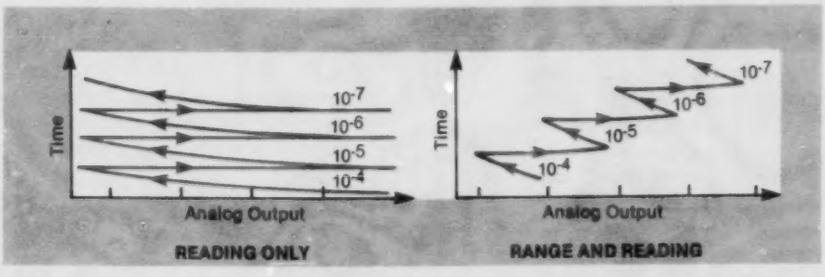


Figure 1. **Strip-Chart Recordings** like these would be obtained from typical pressure readings in a vacuum system during pumpdown. In the curve at the left, the BCD digital vacuum-gage output has been processed by the analog-to-digital converter in such a way that only the reading digits (but not the range) appear in the output. In the curve at the right, the range has also been converted to analog and placed as the most significant digit.

zation gages produce an analog output voltage that is proportional to the pressure. Depending on the specific instrument, the analog output may represent the "reading" only (for example, 5.2) with no information about the "range" (10^{-6}); or it may represent the logarithm of both. Newer instruments now make pressure data available in the form of binary-coded decimal (BCD) digits — two digits for the reading plus one digit for the range. Conversion of BCD data to an analog voltage signal is straightforward; there are many IC's on the market for this purpose.

The problem is what is the most suitable form for converting the BCD data to strip-chart recording. Figure 1 (left) shows a pumpdown trace in which the pressure starts at 1×10^{-3} torr (1.3×10^{-1} Pa) and decreases by a factor of 2 per unit time to 1×10^{-7} torr (1.3×10^{-5} Pa).

This sketch represents the analog conversion of only the reading digits. The change from one decade to the next is obvious, but from which range to which is unknown, unless the range is recorded on a second channel or entered manually on the chart. Figure 1 (right) shows the same pumpdown with the range also converted to analog and placed as the most significant digit. This trace is quite confusing at first sight. Convention leads one to expect the data to decrease in magnitude from right to left in a regular way, not decrease for a bit, then increase abruptly only to decrease again. This behavior is caused by the fact that the ranges are negative powers of 10, so that a larger range number is in fact a lower pressure.

To present the data in a more logical form, a pseudologarithmic digital-to-analog converter with the following characteristics is desired:

1. The analog output voltage increases as the pressure increases;
2. Each decade in pressure (range) is represented by an equal increment of voltage; and
3. Within each pressure decade, the reading digits are converted linearly (not logarithmically); that is, 5 is half the way between 1 and 10.

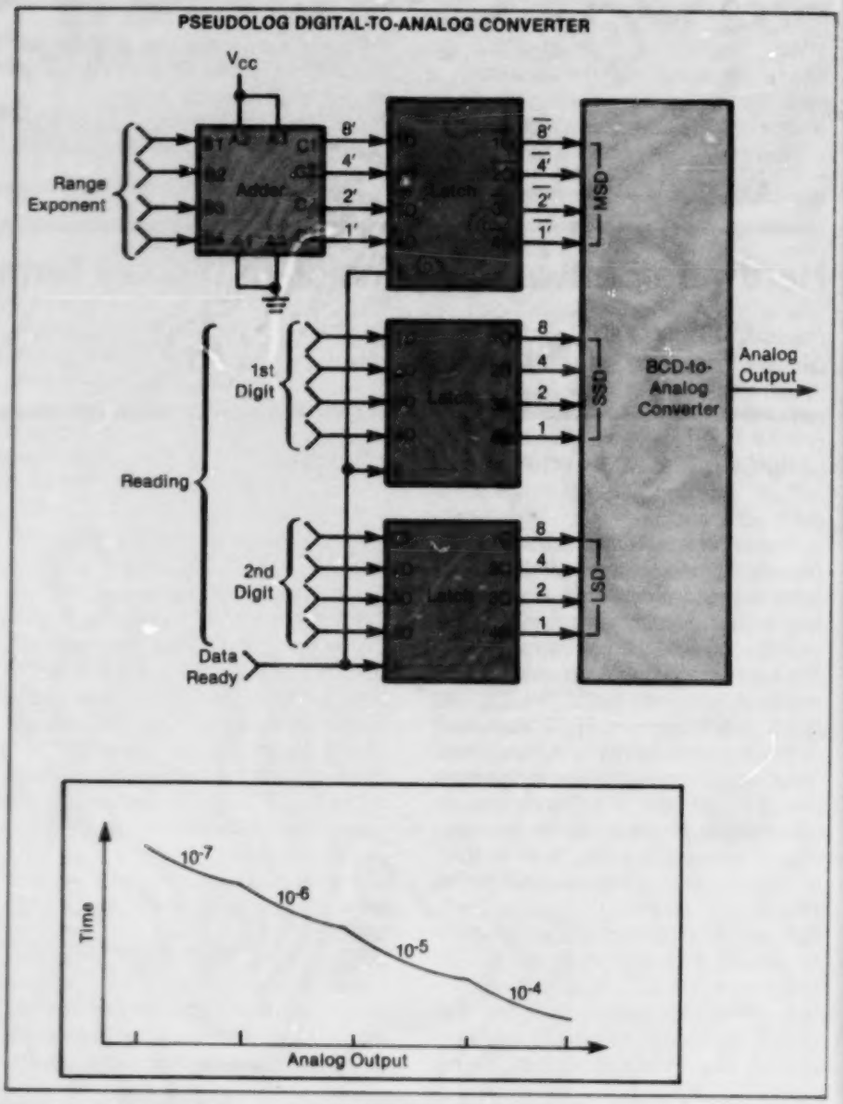


Figure 2. The Pseudolog Converter would produce a strip-chart recording with continuous analog coverage of the entire pumpdown pressure history. The ends (1, 10, 100, etc.) of the decades appear at equal voltage intervals in the output, but within each decade the output varies linearly with the input.

As shown in Figure 2, only the range digit needs to be manipulated before being converted into an analog voltage. First a suitable binary mask (see below) is applied to the range using a 4-bit binary adder. The masking addend is hard wired on the adder, and the carry bit is ignored. The outputs of the adder then become the inputs to a 4-bit bistable latch. When the ionization gage signals "data ready," the input bits of the latch are transferred to its outputs. The inverted outputs from the range latch are then used as the most significant digit (MSD) to a standard BCD digital-to-analog converter. The two digits for the readings are also loaded into latches and become the second most (SSD) and least (LSD) significant digits for analog conversion. Figure 2 shows the same pumpdown as Figure 1, but seen through the eyes of the pseudolog converter.

The scalloped appearance is caused by the nonlogarithmic conversion of the reading digits; that is, 5 is halfway between 1 and 10, not seven-tenths of the way as it would be for true log conversion.

The binary mask for the range is selected to set the lowest decade to be converted; that is, which power of 10 is to appear as zero volts. For the circuit shown, the 10^{-9} decade falls between 0.00 and 0.99 volt, and the 10^{-8} decade runs from 1.00 to 1.99 volts. Full-scale (9.99) volts are 9.9×10^{0}. The mask choice is simple; the sum of the lowest decade desired and the mask must be 15 in decimal (1111 in binary). In this case, 9 is 1001, so the required mask is 6 (0110). When their sum (1111) is inverted (0000) and passed to the converter, it appears as 0 volts. Similarly, for a lowest range of 10^{-7}, the mask is 8 (1000).

This work was done by Suzanne T. Gooder of **Lewis Research Center.** *No further documentation is available.*
LEW-14219

Microwave Sensor Measures Turbopump Speed

The sensor does not perturb the flow and is immune to cavitation.

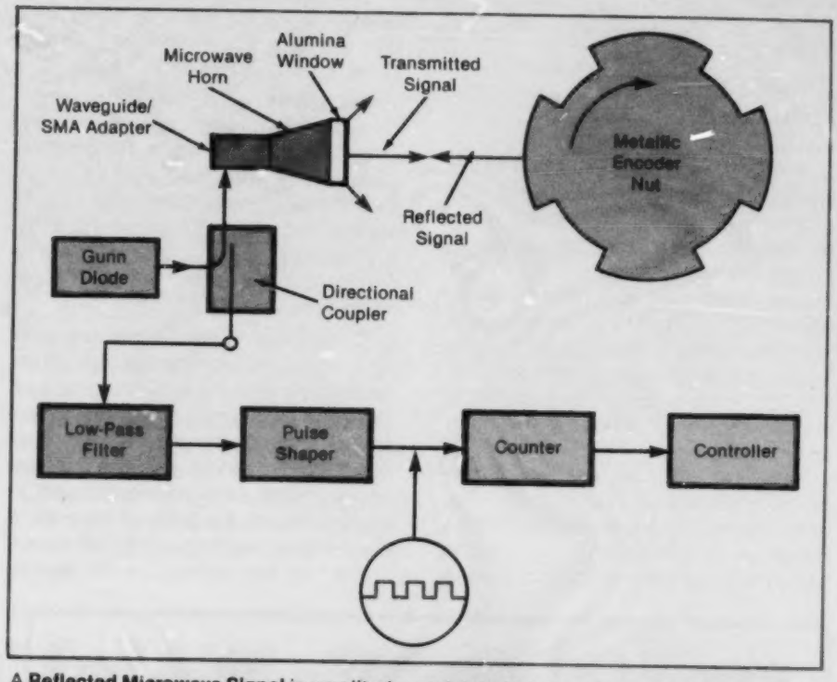
Marshall Space Flight Center, Alabama

A microwave device measures the rotational speed of a turbopump without obstructing the flow. In contrast, a magnetic or capacitive speed sensor protrudes into the flow in proximity to the rotating shaft, thereby disturbing the flow and risking damage to the sensor and the machine. While nonintrusive optical speed sensors are available, they do not operate correctly when the pumped fluid cavitates.

The microwave speed sensor is illustrated schematically in the figure. A microwave antenna in the pump housing sends a continuous signal to a lobed, reflective encoder nut on the rotating shaft. The signal returned to the antenna is modulated by the reflections from the passing lobes.

The returned signal is detected and low-pass filtered to extract the modulation, the frequency of which is proportional to the rotational speed. The filtered signal is fed to a pulse shaper. The shaped pulses are counted along with a timing pulse train to obtain the modulation frequency and, therefore, the rotational speed.

The microwave frequency must be selected so that cavitation in the pumped fluid has a negligible effect on the returned signal. For example, bubbles in nonane do not affect the microwave transmittance strongly at frequencies near 15 GHz, so that the sensor is insensitive to cavitation.



A Reflected Microwave Signal is amplitude-modulated by the passing reflective facets of a nut on the rotating shaft. The modulation frequency is measured to find the rotational speed.

This work was done by J. M. Maram and L. Wyett of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-28083

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Simulating Single-Event Upsets in Bipolar RAM's

This simulation technique can save much testing.

A technical paper presents the results of computer simulations of single-event upsets in bipolar integrated circuits — particularly random-access memories (RAM's). A companion paper discusses experiments to check the accuracy of the simulation.

Although metal-oxide-semiconductor (MOS) integrated circuits have received more attention, bipolar chips are also susceptible to single-event upsets and will become even more so as they are made smaller. Also known as single-particle soft-error generation, this phenomenon is manifested as a bit flip in a flip-flop or a RAM cell. It occurs when an energetic heavy ion traverses a transistor or diode in a chip.

The simulation uses an interactive version of SPICE (Simulation Program with Integrated Circuit Emphasis). The device and subcircuit models available in the software are used to construct a macromodel for an integrated bipolar transistor. Time-dependent current generators are placed inside the transistor macromodel to simulate charge collection from an ion track.

In the experiments, a Van de Graaff accelerator was used to measure the single-event upset cross section as a function of the kinetic energy of positively-charged bromine ions for both unaddressed and addressed cells loaded with either all ones or all zeros. For the addressed cells, most of the measured values agreed within experimental error with the values calculated in the computer simulation.

A significant finding of the experiments is that the standard design practice of reducing the power in an unaddressed bipolar RAM cell increases the sensitivity of the cell to single-event upsets. The reason for this is that a RAM cell operating in the unaddressed, standby mode responds more slowly and allows charge to collect over a longer time period. An unaddressed cell may respond to an ion track anywhere in the bipolar transistor through charge collection at all junctions.

This work was done by John A. Zoutendyk of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain copies of the re-*

ports, "Soft-Error Generation due to Heavy-Ion Tracks in Bipolar Microcircuits" and "Experimental Determination of Single-Event Upset (SEU) as a Function of Collected Charge in Bipolar Integrated Circuits," Circle 2 on the TSP Request Card.
NPO-16491

Plasma Source for Charge Control

Electrical charges on a spacecraft would be neutralized.

A plasma source would neutralize the electrical charge on a spacecraft, according to a preliminary report. When triggered by a command from the spacecraft potential monitor or from the control system, the plasma apparatus would respond within about 1 s, generating a charged plasma of the required polarity. The discharging system is to be tested on the Air Force Geophysics Laboratory BERT-1 (Beam Emission Rocket Test) sounding rocket.

The source includes a rapidly-starting hollow cathode in a containment vessel, with a biasing keeper electrode to control the plasma flux. The working gas used to generate the plasma is fed from a reservoir to the source through a latching valve, pressure regulator, and flow-metering valve.

A lightweight power supply operating on 28-V input includes separate starting and running converters for rapid starting and the establishment of a stable plasma in the cathode barrel. The discharge current in the cathode is maintained at 2 A in all operating modes. The particle flux from the cathode is preset at 0, 0.3, 1.2, or 2.0 A by setting the keeper bias. This bias can be positive to collect electrons or negative to collect positive ions.

The plasma source is electrically connected to the spacecraft through a current-sensing resistor. A current-integrating circuit indicates the magnitude and polarity of the total charge leaving the plasma source: This measurement helps to quantify the degree of spacecraft charge buildup and the efficacy of the charge-neutralizing apparatus.

Three different sets of experiments will be conducted during the test flight. In the first set, the vehicle will be charged by an electron gun, ion gun, or capillaritron ion source, then discharged by the plasma source, all at various altitudes, plasma-source modes, and vehicle charges. In the second set, the ability of the plasma source to prevent charging will be examined by first turning on the plasma source, then attempting to induce a charge with one of the artificial sources. In the third set, a plate will be biased at −500, −1,000, or 2,000 V to examine current collection from the plasma source at these biases.

This work was done by Graeme Aston, Lewis C. Pless, and William D. Deininger of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Plasma Source for Spacecraft Charge Control," Circle 95 on the TSP Request Card.*
NPO-16576

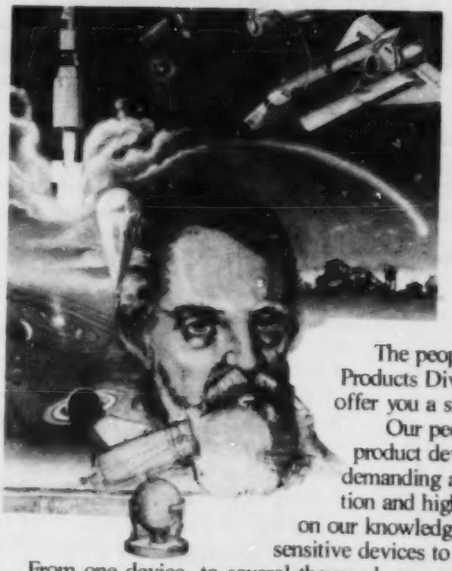
Single-Event Upsets Caused by High-Energy Protons

Heavy secondary ions do not significantly alter device responses.

Concern that nuclear reaction products generated by protons external to a digital integrated circuit might increase the number of single-event upsets in the circuit is unfounded, according to a report. The report is based on a study in which 10 types of digital integrated circuits were subjected to 590-MeV protons. The concern evolved from the possibility that heavy ions produced by protons striking an integrated circuit, the circuit lid, and even shielding near the circuit could lead to high rates of single-event upset.

The study was done to clarify the understanding of single-event upsets caused by high-energy protons like those found in galactic cosmic rays, solar flares, and belts of trapped radiation. It examined the relationship between single-event-upset cross sections and proton energy, the effect of nuclear reaction products from metal overlayers (including device lids), and the influence of the angle of incidence of the radiation. The devices tested included 1K random-access memories, 4-bit microprocessor bit-slices, 9-bit data registers, a 4-bit shift register, an octal flip-flop, and a 4-bit counter.

The conclusion that external reaction products cause no significant alteration of single-event-upset response was based on a comparison of data obtained from both lidded and unlidded devices and for proton beams impinging at angles ranging from 0° to 180° with respect to the chip face. The study also found that the single-event-upset cross section increases only modestly as proton energy is increased to 590 MeV, which is characteristic of the maximum energies expected in the belts of trapped protons surrounding Earth and Jupiter.



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Circle Reader Action No. 403

The devices most susceptible to protons were the same as those most susceptible to heavy ions. The correspondence is not exact, however; a proton can occasionally induce single-event upset in a relatively insensitive device when a nuclear reaction deposits an unusually large amount of energy.

This work was done by William E. Price, Donald K. Nichols, Lawrence S. Smith, and George A. Soli of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "The Single Event Upset (SEU) Response to 590 MeV Protons," Circle 61 on the TSP Request Card.*
NPO-16504

Hyperspectral Infrared Images of Terrain

Images at 128 wavelengths allow direct identification of many earth surface materials.

Two reports describe an advanced airborne spectrometer that creates images of terrain at many wavelengths. It can be used for agricultural, geological, and other surveys. The system was described previously in "Imaging Spectrometer for Geophysical Surveys" (NPO-16072) on page 76 of *NASA Tech Briefs*, Vol. 9, No. 1.

The airborne imaging spectrometer (AIS) produces two-dimensional images in 128 spectral bands in the 1.2-to-2.4-micrometer wavelength region. The images are created by a 32-by-32 array of mercury cadmium telluride detector elements. The array views a swath of Earth below the moving aircraft.

Light is collected by reflecting foreoptics and focused on a slit, which defines the width of the track on the ground. The combined foreoptics and spectrometer optics provide a focal length of 36 millimeters and a field of view of 1.9 milliradians per pixel. Light passing through the slit is dispersed by a grating in the spectrometer, then refocused on the detector array. Thus, an image line 32 pixels wide is repeated simultaneously at 32 wavelengths along the length of the array. The grating is stepped through four positions during each image-line period, producing lines at a total of 128 contiguous wavelengths.

The detector array is cooled by liquid nitrogen. The detectors are mated to a silicon charge-coupled device (CCD) multiplexer: This arrangement allows a relatively long integration time on the detectors, which can then be read out to the multiplexer quickly. While the signal is being read out from the multiplexer at a more leisurely rate, the detectors are integrating new signals.

The electronic equipment for the spectrometer is packaged in a two-bay, aircraft-compatible rack, 1½ meters high. The rack contains a control panel, analog and digital electronics, a programable word generator, clock drivers, power panel, oscilloscope, recording altimeter, and tape recorder. The AIS is controlled by commands entered from the control panel keypad.

The digital electronics, which provide the clock signals that control the detector array, consist of a single-board computer, a programable waveform generator, clock drivers, and interface electronics. The digital electronics also control the grating drive, the film camera, a calibration lamp, and the tape recorder. The analog electronics connect with the detector array through two parallel paths, each containing a voltage amplifier and a dual correlated sample-and-hold circuit.

This work was done by Gregg Vane, Alexander F. H. Goetz, John B. Wellman, and Clayton C. LaBaw of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the reports "Airborne Imaging Spectrometer: A New Tool for Remote Sensing" and "Experiments in Infrared Multispectral Mapping of Earth Resources," Circle 30 on the TSP Request Card. NPO-16295*

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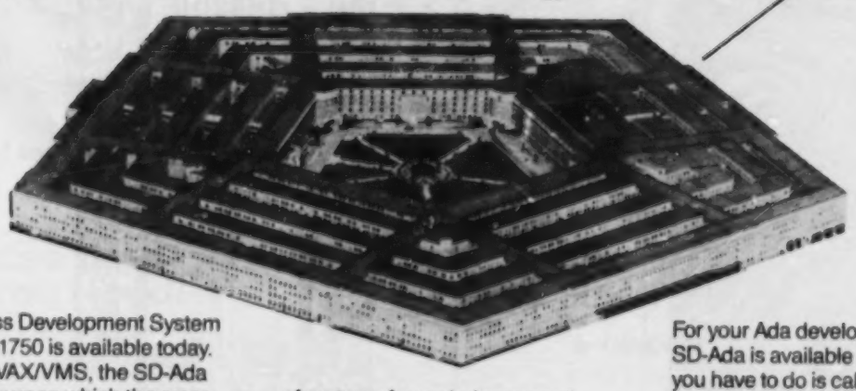

SD-Ada Cross Development System for MIL-STD-1750 is available today. Running on VAX/VMS, the SD-Ada host compiler upon which the cross development system is based is DoD validated, and implements the full ANSI/MIL-STD-1815A language standard as well as uses the DoD-approved DIANA Ada intermediate language.

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Circle Reader Action No. 303

Physical Sciences

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Seebeck Coefficient Measured With Differential Heat Pulses

Common experimental errors are reduced because the pulse technique suppresses drifts in thermoelectric measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

A differential-heat-pulse apparatus measures the Seebeck coefficient in semiconductors at temperatures up to 1,900 K. The output is a plot of the Seebeck voltage versus the temperature difference, the slope of which is the Seebeck coefficient. Because a pulse technique is used, the errors that often arise from long-term drifts in thermoelectric measurements are suppressed. The apparatus works with temperature differences of only a few degrees, thereby further increasing the accuracy of the coefficients so obtained.

The sample is placed in a furnace (see Figure 1) in a vacuum. The Nb wires of Nb/W thermocouples make contact with the upper and lower ends of the sample. Sapphire light pipes conduct infrared radiation from two light bulbs to the opposite ends of the sample.

Initially, the furnace is brought to the measuring temperature. A small current is applied to each light bulb, thereby generating infrared radiation that heat both ends of the sample by the same small amount (of the order of a degree). Then, for the Seebeck measurements, the current of one lamp is increased while the current of the other lamp is decreased by approximately the same amount: The exact amounts are

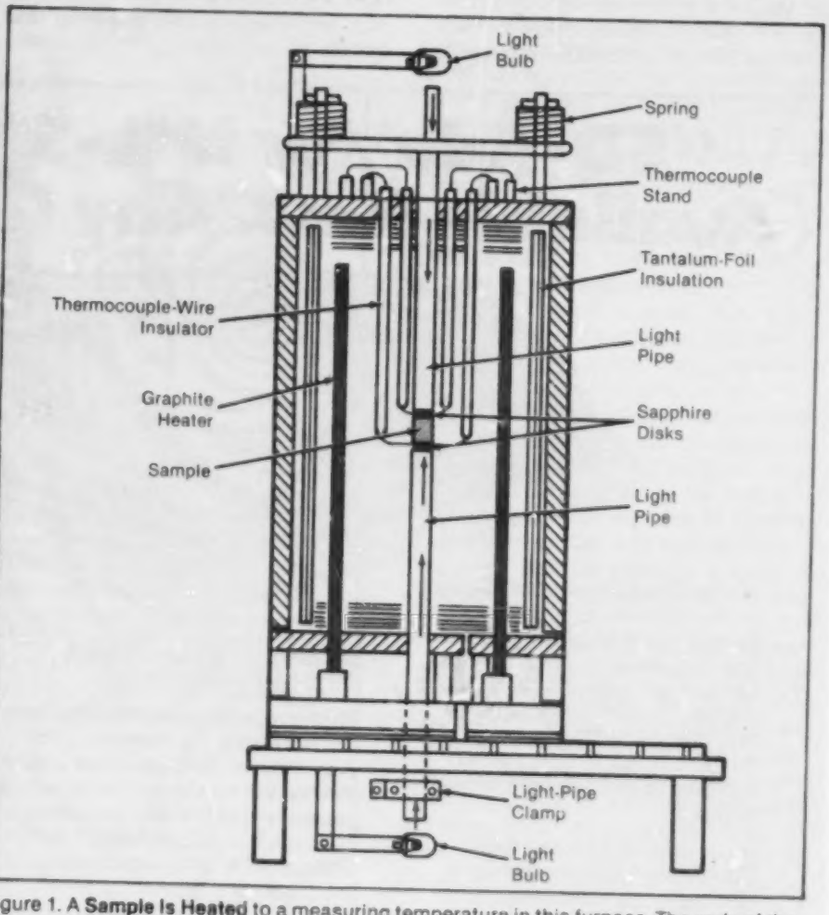
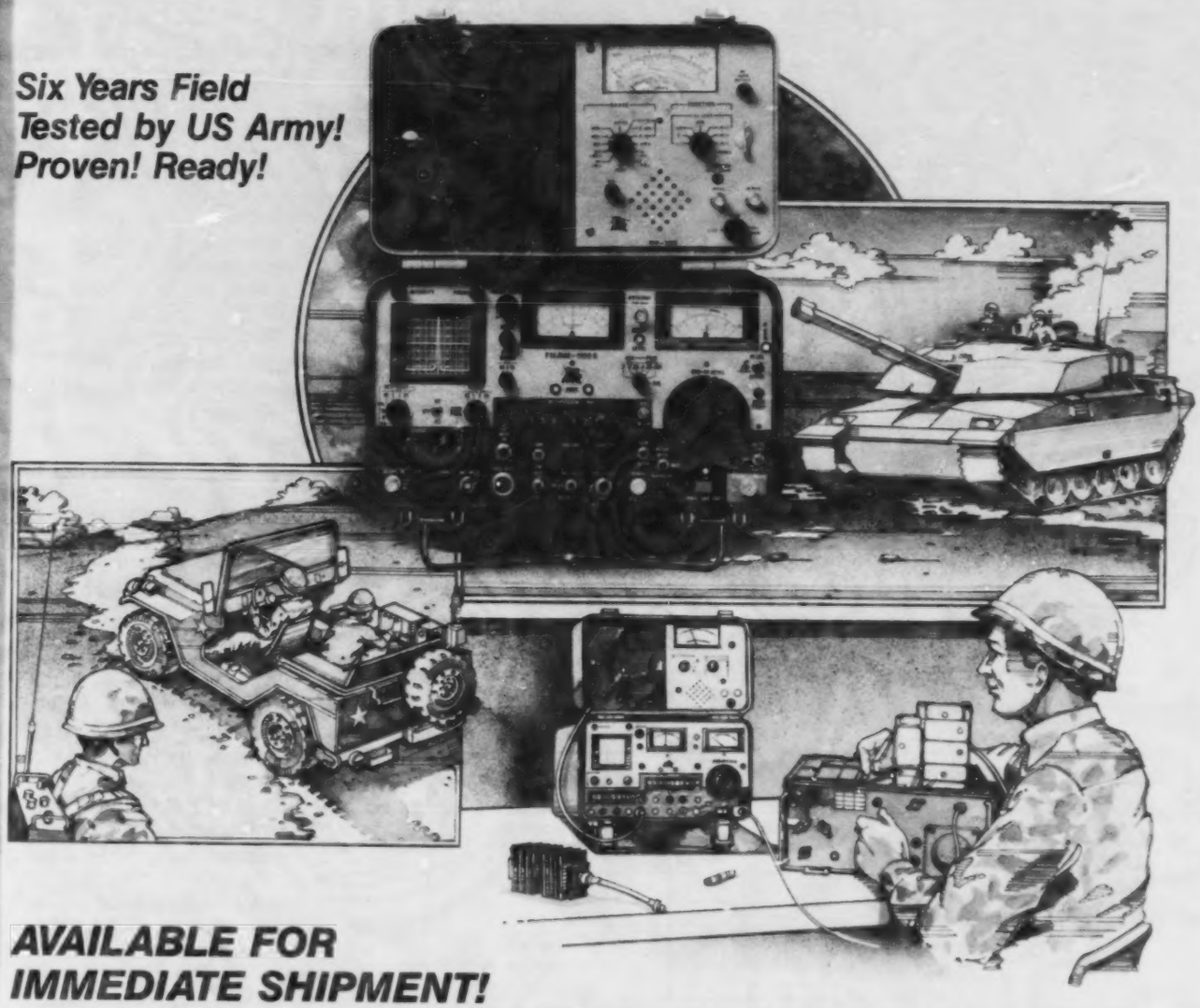


Figure 1. A **Sample Is Heated** to a measuring temperature in this furnace. The ends of the sample are then differentially heated a few degrees more by lamps. The differential temperature rise and the consequent Seebeck voltage are measured via the thermocouple leads.



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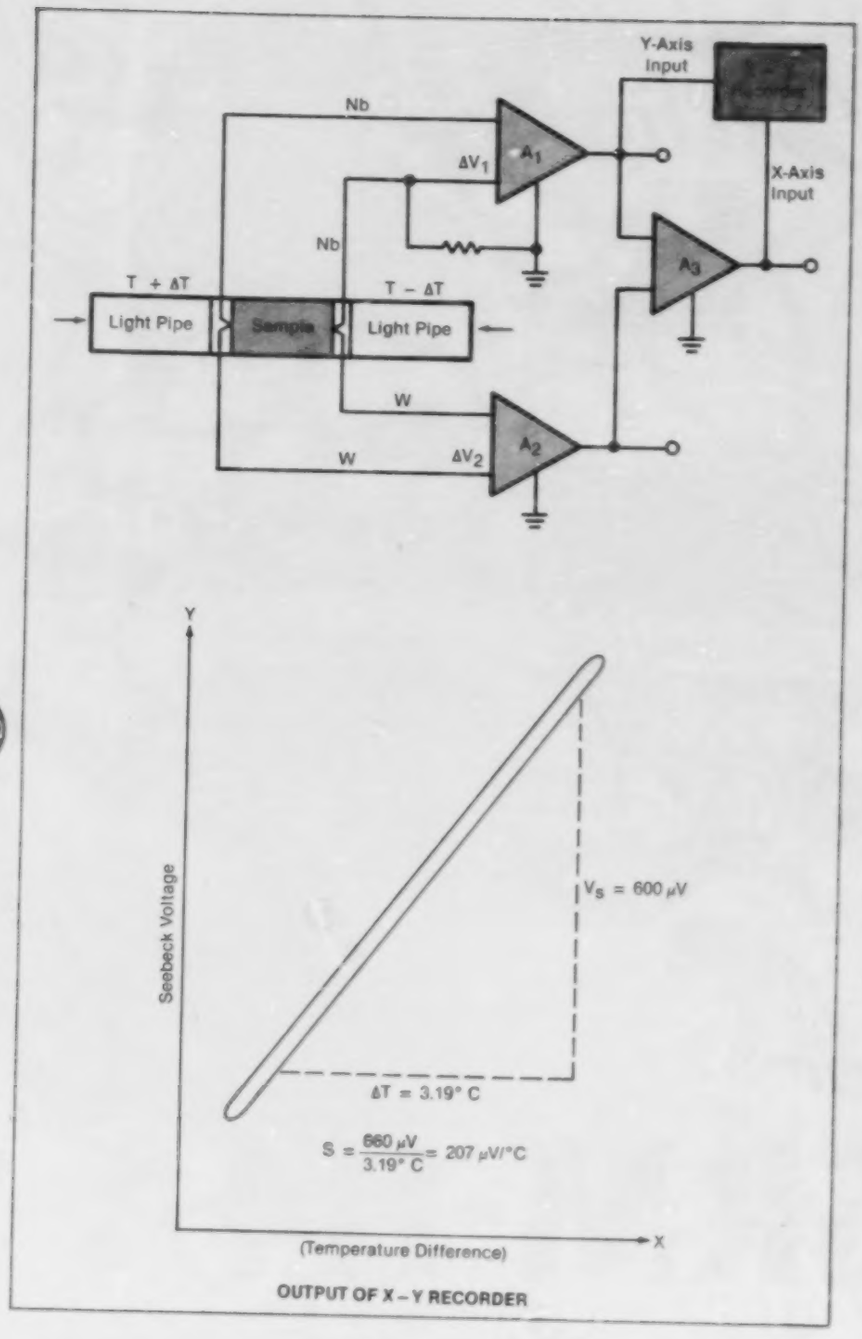

chosen so that the temperature rise at one end increases while the temperature rise at the other end decreases, but the average temperature rise of the sample remains the same as in the initial setting.

As shown in Figure 2, the thermocouple leads are used to measure both the temperature difference between the sample ends and the Seebeck voltage, which is the voltage between the sample ends that arises by virtue of the temperature difference. Since Nb is known from previous measurements to have a negligible Seebeck voltage, the voltage between the Nb thermocouple leads can be assumed equal to the Seebeck voltage of the sample for practical purposes. This signal is fed to amplifier A_1, the output of which drives the Y-axis motion of an X-Y recorder.

The difference between the voltage on the Nb wire pair (ΔV_1) and the voltage on the W wire pair (ΔV_2) is essentially the difference between the thermocouple outputs and therefore is proportional to the temperature difference between the ends of the sample. The output of amplifier A_3 is proportional to $\Delta V_1 - \Delta V_2$ and is fed to the X input of the X-Y recorder for display as the temperature difference. Thus, as a differential heat pulse causes a shift along the differential-temperature (X) axis, it also causes a shift along the Seebeck-voltage (Y) axis, yielding a direct plot of the Seebeck effect in the sample.

This work was done by Leslie Zoltan, Charles Wood, and Gerhard Stapfer of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 13 on the TSP Request Card.*
NPO-16506

Figure 2. The **Seebeck and Differential Thermocouple Voltages** are separated from each other by subtraction in amplifier A_1. These voltages are then fed to an X-Y recorder. The recording shown here was taken on a sample of B_4C_2 at 450°C. The hysteresis in the plot is probably an inherent measurement error due to temperature differences between the sample and the thermocouples.

Brewster-Plate Spoiler for Laser Spectrometer

Unwanted interference effects are reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

An oscillating Brewster plate reduces the effects of unwanted interference fringes on absorption-spectroscopic measurements obtained with tuned diode lasers. The fringes arise from reflections of laser beams at the surfaces of windows, lenses, and other optical elements. These fringes become superimposed on the absorption spectra and are particularly troublesome during measurements of molecular absorptions smaller than 0.01 percent.

The oscillating plate, or spoiler, is mounted in the laser-beam path between the surfaces that cause the fringes (see figure). It is oriented at the Brewster angle

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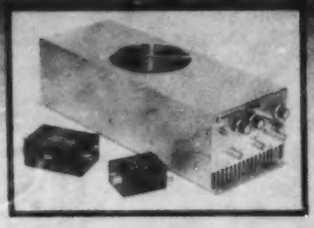
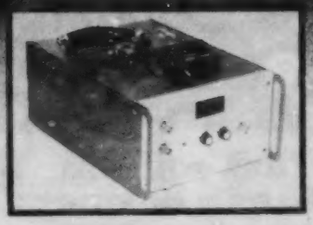
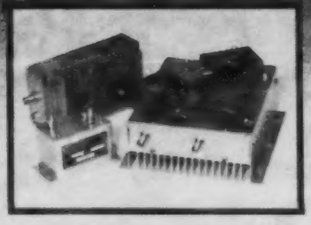

MODULATORS

MODEL	WAVELENGTH	EFFICIENCY %	MOD. BW MHz @ mm	RISE TIME nsec	ACTIVE APERTURE	BEAM SEPARATION	DRIVE ELECTRONICS
AOM-70U	300-400 nm	80	30 @ .14	16	1 mm	4.27 mr	ME-70
AOM-125B	442 nm	80	30 @ .1	16	.6 mm	14.3 mr	MOP-125
AOM-40	440-700 nm	90	4.5 @ .65	110	2 mm	6.5 mr	ME-40
AOM-80	440-700 nm	80	15 @ .18	35	1 mm	13.9 mr	ME-80
AOM-110	440-700 nm	70	20 @ .14	24	.6 mm	19.2 mr	ME-110
AOM-125	440-700 nm	70	20 @ .14	22	.6 mm	20.5 mr	ME-125
AOM-40R	1.06 um	80	2.9 @ 1	170	2 mm	10.8 mr	ME-40R
AGM-406B	10.6 um	80	.68 @ 6	700	6 mm	77 mr	GE-4040

INTRA-CAVITY MODULATORS

MODEL	WAVELENGTH	TYPE	EFFICIENCY % @ WATTS	CENTER FREQ.	FEATURES	DRIVE ELECTRONICS
AQS-244A	1.06 um	Q-SWITCH	40 @ 10	24 MHz	HIGH EFFICIENCY	QE-2425
AQS-244B	1.06 um	Q-SWITCH	40 @ 40	24 MHz	POL. INSENSITIVE	QE-2450
AQS-244C	.4-1.3 um	Q-SWITCH	40 @ 10	24 MHz	BREWSTER WINDOW	QE-2425
AQS-247B	1.06 um	Q-SWITCH	40 @ 65	24 MHz	LARGE APERTURE	QE-2475
AQS-504A	1.06 um	Q-SWITCH	40 @ 15	50 MHz	HIGH EFFICIENCY	QE-5025
ML-50Q	1.06 um	MODE LOCKER	50 @ 5	50 MHz*	BREWSTER WINDOW	MLE-6A
ML-70B	1.06 um	MODE LOCKER	50 @ 5	70 MHz*	2° RHOMBOID	MLE-*

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DEFLECTORS

MODEL	TIME B W spots	ACCESS TIME u sec.	EFFICIENCY %	BANDWIDTH	APERTURE	SCAN RATE	DRIVER (MOD. OPT.)
ADM-40	100	5	85	20 MHz	2 x 20 mm	40 KHz	DE-40 (M)
ADM-70	200	5	80	40 MHz	2 x 20 mm	40 KHz	DE-70 (M)
AOD-70	400	10	80	40 MHz	2 x 40 mm	20 KHz	DE-70 (M)
ADM-150	500	5	60	100 MHz	1.3 x 20 mm	40 KHz	DE-150 (M)
AOD-150	1000	10	60	100 MHz	1.3 x 40 mm	20 KHz	DE-150 (M)
AOD-150B	1000	10	70	100 MHz	1.3 x 40 mm	20 KHz	DE-150 (M)

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Despite "promising" economic forecasts and the public's patient "wait and see" attitude, the deficit is at record levels. So is wasteful and inefficient spending in government.

Many executives are openly decrying the deficit as the one thing that can derail the economy in 1985 and beyond. Among the consequences:

- A collision between the private sector and the U.S. Treasury for access to the credit markets.
- Reduced worth of personal and corporate portfolios.
- Increased taxes that will slash growth and inspire layoffs.
- The transfer of a bigger deficit and unwieldly debt to the next generation.

Business leaders need to get the attention of those politicians and bureaucrats who are dragging their feet in cutting waste and inefficiency in government.

Fortunately, the hard work is already done

The ground work has been laid by the Grace Commission Report, which details 2,478 ways to reduce federal waste, inefficiency and overspending. Once adopted these proposals would save $424.4 billion over three years, and effectively get America out of hock.

The report provides solid evidence that government waste and inefficiency can be reduced. It provides practical ways to cut waste without weakening our national defense and eliminating necessary subsidy programs.

What you can do as a business leader

We need your help to distribute the Citizens Against Waste Petition to be served on the 99th Congress, to let the lawmakers know there's some real pressure building among their constituents to cut the deficit and stop waste.

Sponsor a petition center that includes a 24" x 37" Poster for display and the 500-petition display (a 10,000-name potential).

The cost is only $40.00 delivered prepaid.

The display takes up less than one square foot of space and is an investment that is sound business practice for all concerned.

The deficit is the one economic culprit that can single handedly derail the economy, slash growth, inspire layoffs and reduce the worth of personal and business finances — not only for 1985, but for years to come.

It is essential that more and more Americans pool their efforts and their money to establish a vocal and powerful group to pressure those politicians and bureaucrats who insist on wasting tax dollars and using government funds for their own pet projects.

Not to mention, the urgent need for all public officials to become more accountable, answerable, and responsive to the American taxpayer.

Pressure works!

Politicians do and will respond if the numbers of petitions are big enough.

In fact, they'll buckle under.

It's been proven in the past that pressure works. From the Child Labor Law, the Women's Right To Vote, Workmen's Compensation, the Civil Rights Act, and the recent and very successful efforts to curb drunk driving by SADD and MADD, we have seen that Congress WILL respond time and again. But only when they're convinced that the people are serious.

A Petition to Our Government

As the true owners of the U.S. government, we protest the appalling waste of our money by those we entrust to spend it. We demand action, not discussion, to stop the excessive and unnecessary squandering of government funds for foolish projects, wasteful programs and inefficient operations. We want corrective measures taken against those in Congress and the federal bureaucracy who irresponsibly authorize and misspend our tax dollars.

Citizens Against Waste — Who We Are

Citizens Against Waste is a nonprofit foundation of bipartisan and concerned citizens from all walks of life, who've come together to "educate" the Federal bureaucratic spenders and waste makers in Congress about the absolute necessity to curb overspending, waste and inefficiency to eliminate the deficit.

Citizens Against Waste
1511 K Street NW,
Washington, D.C. 20005

ATTN: J. P. Bolduc, President

Dear Mr. Bolduc:

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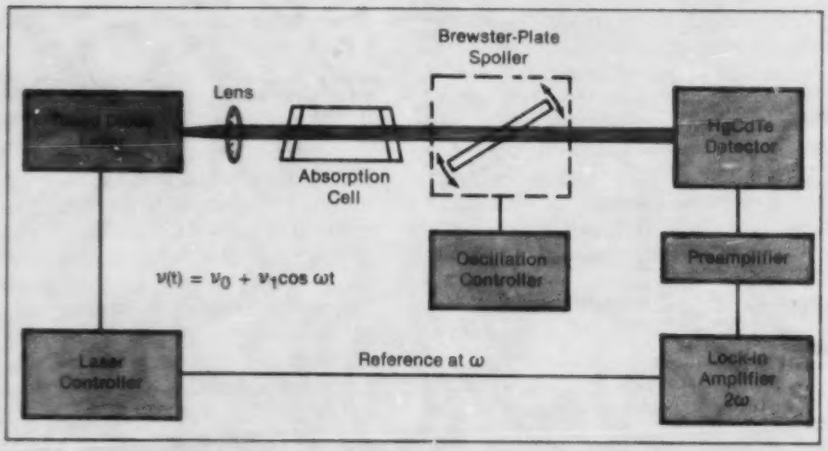
(the angle at which the beam component polarized in the plane of incidence is not reflected from the first surface) to minimize reflection losses when polarized laser beams are used. The plate is oscillated about the Brewster angle with an amplitude up to a few degrees: This varies the optical path length, thereby changing the resonant frequency of the optical cavity defined by the fringe-producing surfaces and altering the fringe pattern. The rapid oscillation blurs the fringes; that is, the time-averaged fringe effect is reduced.

The plate material must be substantially transparent at the laser wavelength. The plate must not be so thick that it introduces excessive beam aberrations or is too massive to oscillate conveniently, but must be thick enough so that it will not break and so that, at the chosen oscillation amplitude, the cavity length is scanned past several resonance peaks.

The plate may be driven by a galvanometer, for example. A waveform generator drives the galvanometer. The best oscillation waveform for fringe averaging is usually a triangular wave because, unlike others (for example, a sinusoid or a square wave), it does not cause the plate to dwell for a substantial portion of the time at or near the turning points.

The oscillation causes some unwanted amplitude modulation of the laser beam. Consequently, the oscillation frequency must be high enough to cause an averaging of the fringe pattern in an interval less than the time to scan the tunable laser over half the fringe period. The frequency must also lie outside the passband of the lock-in amplifier.



The Oscillating Brewster Plate modulates the optical-path length past several resonance peaks causing interference fringes to pass by rapidly and become blurred. Thus, the fringe effects are averaged out over time.

A Brewster-plate spoiler was demonstrated successfully in absorption measurements on N_2O: Weak absorption lines that were masked by interference fringes could be distinguished when the spoiler was turned on. For tunable-diode laser spectroscopy in the midinfrared region, the spoiler technique is expected to enable the detection of absorptances less than 10^{-5} in single laser scans. The technique can also be used at other wavelengths from ultraviolet to infrared and in spectrometers with short or long optical paths, including those with retroreflectors or multipass cells.

This work was done by Christopher R. Webster of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 87 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 21]. Refer to NPO-16567.

Test Method for X-Ray Telescopes

Ring images reveal surface deviations.

Marshall Space Flight Center, Alabama

Telescopes in general, and X-ray telescopes in particular, could be tested with nearby point sources of radiation. When point-source rays enter a telescope through an annular entrance pupil (and under conditions of spherical aberration), a ring image is produced. The deviation of this ring image from a perfect circular shape reveals misalinements and sur-

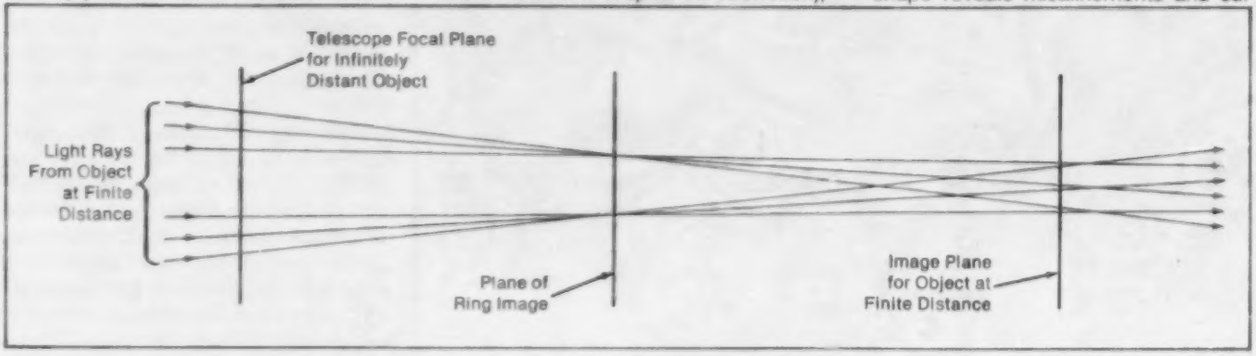

Telescope Focal Plane for Infinitely Distant Object
Light Rays From Object at Finite Distance
Plane of Ring Image
Image Plane for Object at Finite Distance

Figure 1. **A Ring Image Is Formed** by a telescope when a point light source is placed on the telescope optical axis at a finite distance.

face inaccuracies in the telescope. Although particularly suited for grazing-incidence types of systems, this test method can be applied to other types of optical systems as well.

Because of the difficulty of producing a large-diameter, collimated X-ray beam, an X-ray telescope is usually tested with a point source at a finite distance. However, because telescopes are optimized for maximum resolution of infinitely distant targets, this resolution decreases for closer targets. For example, if an astronomical X-ray telescope assembly were tested conventionally in an X-ray facility [at an object distance of about 1,000 ft (305 m)], the resolution would decrease by a factor of 5 to 6, making the test results imprecise. An extension of the X-ray facility would increase the precision but would be very expensive.

These problems could be avoided in the new test method, which would exploit the ring image formed by an imaging system with an annular entrance pupil under conditions of spherical aberration. Spherical aberration can always be introduced in an imaging system with a point source positioned on the optical axis, away from its design distance. In the case of a telescope, spherical aberration is introduced by using a finite object distance (see Figure 1). The very sharp ring image is located a particular distance away from the blurred image of the point object, depending upon the amount and sign of the aberration.

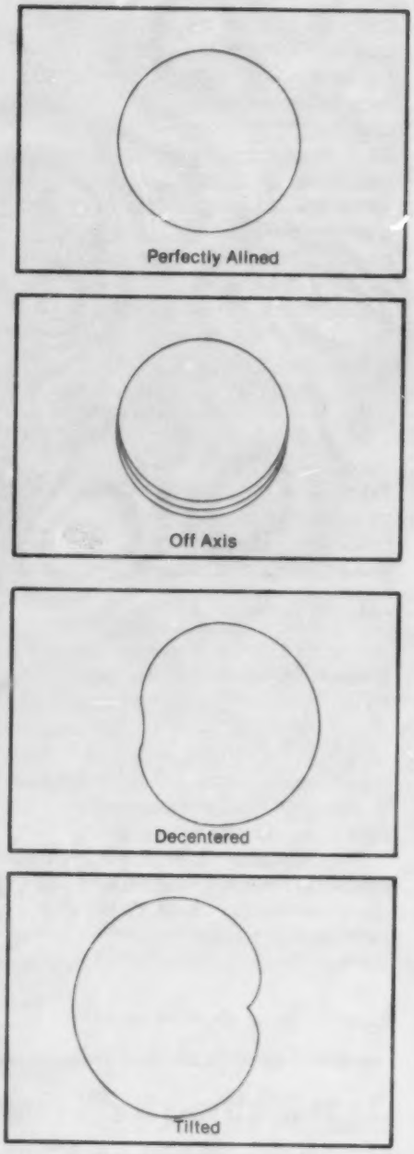


Figure 2. **Misalinements and Surface Irregularities** in telescope systems can be identified from the ring images produced when rays from a nearby point source enter through an annular pupil. The rings shown here resulted from a two-mirror grazing-incidence X-ray telescope with various misalinements.

Because each point of the ring is formed by all rays in the corresponding meridional section, any surface inaccuracy along this section causes the ring to deviate from the perfect circular shape. Characteristic deformations of the ring image also reveal aberrations caused by misalinement. Examples of such ring-image deformations for a two-mirror grazing-incidence telescope are shown in Figure 2. In the case of nested, grazing-

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Circle Reader Action No. 384

incidence telescope systems, each subsystem forms its own ring image, and the concentricity of these images is a further indication of the state of alinement.

This work was done by Dietrich Korsch of Korsch Optics, Inc., for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-26020

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Microwave Power From Natural Emitters

The signal-to-noise ratio of a radiometer system is calculated.

A publication from NASA's Jet Propulsion Laboratory presents calculations of the power radiated from a natural emitter on the Earth to a microwave collecting aperture on an aircraft or a spacecraft. The analysis develops the power-transfer criteria for the detection of the emitting object by the collecting aperture (that is, by the antenna and its receiver). The resulting formulas can be used in the design of radiometer systems.

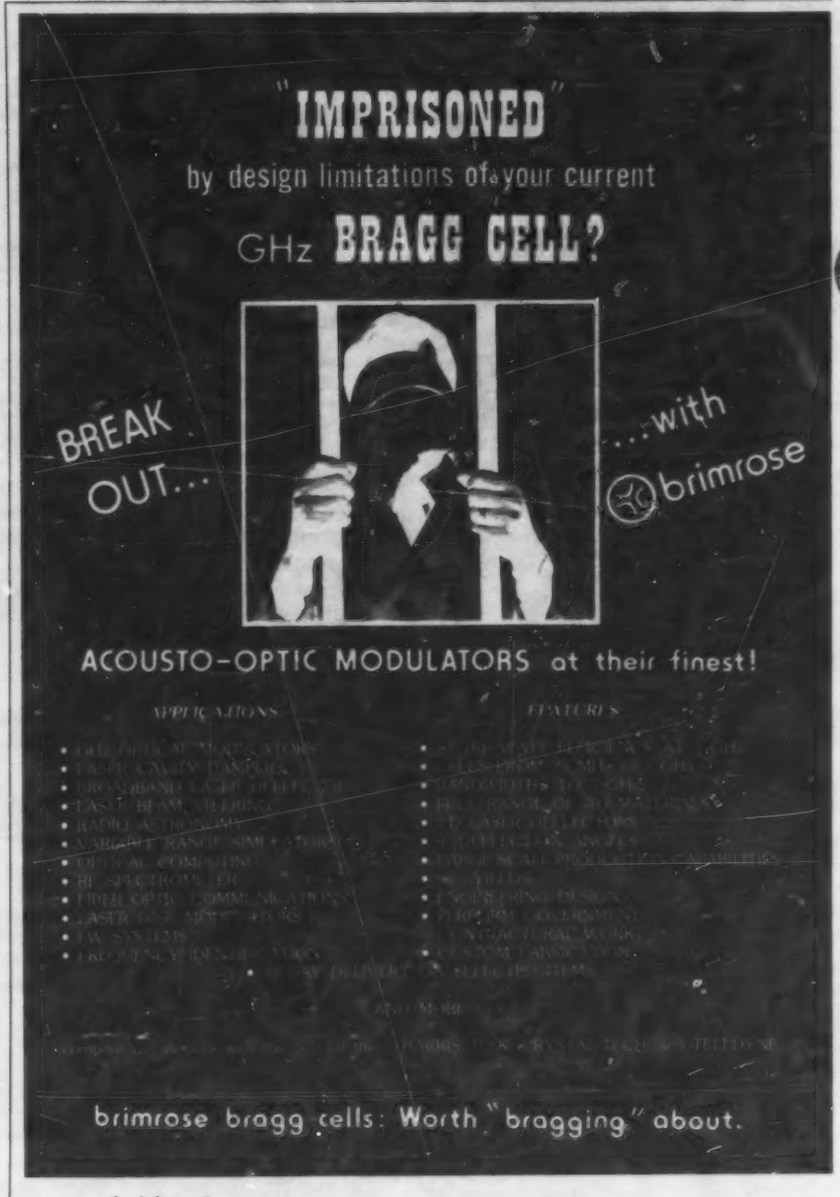
To simplify the analysis, the object is treated as a diffusely-reflecting and diffusely-radiating Lambertian disk emitter on the surface of the Earth, oriented perpendicularly to the Earth's radius. The object is taken to be sufficiently small and the antenna sufficiently high (or both) so that the object can be treated as a point source from the perspective of the receiver.

The total noise in the receiver output is characterized by the orthogonal sum of the clutter-noise temperature and the temperature of the noise generated within the receiver. Clutter noise has several components, including power received along the antenna side lobes from the background or from objects other than the one in view and statistical variations in the component of background radiation that comes in with the object radiation along the main lobe. Clutter irradiances arise especially while scanning across thermal discontinuities like those among forests, bare land, ice, and water. Typically, the clutter power exceeds the rms noise power of the receiver.

The power density arriving at the receiver location from the object is calculated from the object size, emissivity, temperature, distance from the receiver, and direction, using the expressions for Lambertian gray-body radiation. The portion of this power intercepted by the antenna is calculated in terms of the antenna aperture size and the combined collecting efficiency of the aperture and the feed structure for radiation arriving within the main lobe.

An expression is then derived for the signal-to-noise ratio in terms of the foregoing parameters, the receiver bandwidth, and the atmospheric attenuation along the path from the object to the antenna. Since the expression is in closed form, it can also be rearranged to show, for example, the object size or antenna aperture size needed to detect the object with a specified signal-to-noise ratio.

This work was done by Joseph M. Stacey of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the publication, Circle 58 on the TSP Request Card.*
NPO-16581



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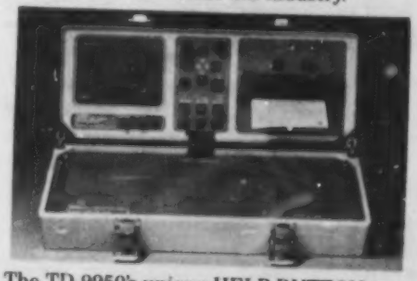
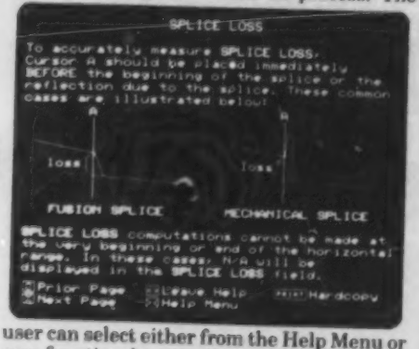


The TD-9950's unique HELP BUTTON provides instant display of operating instructions or on-line application notes. It can be used at any time, for a quick reference, without interfering with work in process. The



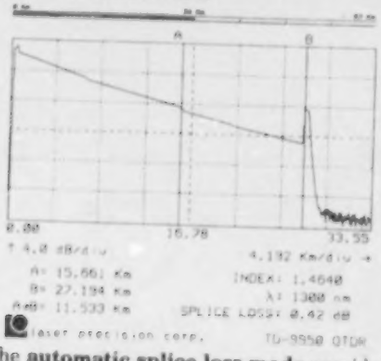
user can select either from the Help Menu or any function key to obtain clear operation instructions.

OPERATES AT ALL WAVELENGTHS

Designed for all wavelengths, the TD-9950 offers plug-in 850, 1300, 1550, and dual wavelength 1300/1550nM modules.

Specifications include: ±0,01% base-accuracy, 0.01dB resolution, 20dB minimum one-way backscatter range, 131 km range, one-meter resolution, dual cursors, and real-time display.

The TD-9950's built-in digital X-Y plotter provides complete data hardcopies for cable system documentation.



The automatic splice loss mode provides instant splice loss measurement, to within 0.01dB, on closely spaced or long distance splices. During splicing or connectorization, the real-time trace and continuous dB readout enable the user to optimize the fiber core alignment.

For more information, contact Laser Precision Corporation, 1231 Hart St., Utica, NY 13502, or call (315) 797-4449.

Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make raw programs available to the public. For information on program price, size, and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

Deformable Subreflector Computed by Geometric Optics

Distorted antenna surfaces are forced to produce a uniform wave front.

SUBFORMING employs geometric optics in determining subreflector coordinates to match a main reflector surface with known distortions. An antenna with a distorted paraboloidal reflecting surface can be forced to produce a uniform wave front by using a Cassegrainian geometry with a path-length-compensating subreflector.

First, the computed distortion vectors of the main reflector are best fitted to a paraboloid. Second, the resulting residual distortion errors are used to determine a compensating subreflector surface by ray tracing, using geometric optics. The solution is a set of points defining the subreflector contour. The slope of the surface and the normal to the surface are determined for each point.

This program is written in FORTRAN V for batch execution and has been implemented on a UNIVAC 1100-series computer with a memory requirement of approximately 25K of 36-bit words. The SUBFORMING program was developed in 1983.

This program was written by William F. Williams of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 18 on the TSP Request Card. NPO-16405*

Computing Composition/ Depth Profiles From X-Ray Diffraction

Diffraction-intensity bands are deconvolved relatively quickly.

TIBAC constructs composition/depth profiles from X-ray diffraction-intensity bands. The intensity band is extremely sensitive to the shape of the composition/depth profile. Numerical interpretation of a band has previously been achieved with trial-and-error matching of known profiles or with prohibitively-expensive computational simulation techniques. TIBAC incorporates a straightforward transformation of the intensity band that retains the accuracy of earlier simulation models, but is several orders of magnitude faster in total computational time.

TIBAC has the following options: Use a deconvolution routine to handle intensity broadening; transform the intensity band into a composition/depth profile; and determine the constant diffusion coefficient for a semi-infinite material. TIBAC will accept monochromatic or doublet X-ray data and will allow for various diffraction geometries, including overlayers and finite films.

The transformation of an intensity band into a composition/depth profile requires that relationships between the composition, d-spacing, linear absorption, and reflectivity be known. These data can be obtained from values in the literature or by outside calculations. The TIBAC output data are in tabular and plotted form, with the final graphs showing the calculated composition (in atomic percent) versus depth (in centimeters), along with the confidence limits and the observed composition/depth profile.

TIBAC is written in FORTRAN 77 for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of 132K (octal) of 60-bit words. TIBAC has also been implemented on an IBM 370-series computer with a central-memory requirement of 267K of 8-bit bytes. For graphic output, the user must supply basic plot routines. TIBAC was developed in 1984.

This program was written by K. E. Wiedemann and J. Unnam of Analytical Services and Materials, Inc., for **Langley Research Center.** *For further information, Circle 78 on the TSP Request Card. LAR-13356*

Thermodynamic Calculations for Complex Chemical Mixtures

A computer program calculates equilibrium compositions and the corresponding thermodynamic and transport properties of these mixtures.

Many processes in existence today involve complex chemical mixtures, frequently at high temperatures. Some of these mixtures result from combustion processes such as those that occur in automobiles, aircraft, and rockets. Others occur in processing equipment in the chemical, petroleum, and natural-gas industries. Research equipment, such as shock tubes, also involves high-temperature gas mixtures. To understand better the nature of these processes, it is necessary to obtain equilibrium compositions and corresponding thermodynamic and transport properties of such complex chemical systems.

A general computer program, CECTRP, has been developed for the calculation of the thermodynamic properties of complex mixtures with an option to calculate transport properties of these mixtures. A free-energy minimization technique is used in the equilibrium calculation. Rigorous equations are used in the transport calculations.

This program has the capability of performing calculations such as (1) chemical equilibrium for assigned thermodynamic states, (2) theoretical rocket performance for both equilibrium and frozen composition during expansion, (3) incident and reflected shock properties, and (4) Chapman-Jonquet detonation properties. Condensed species, as well as gaseous species, are considered in the transport-property calculations.

The thermodynamic properties that are tabulated include pressure, temperature, density, enthalpy, entropy, Gibbs free energy, molecular weight, $(\partial \text{ in } V/\partial \text{ in } P)_T$, $(\partial \text{ in } V/\partial \text{ in } T)_P$, specific heat at constant pressure, isentropic exponent, sonic velocity, and composition. The calculated transport properties are viscosity and thermal conductivity. Specific heat and thermal conductivity are calculated for both frozen and equilibrium conditions. Prandtl and Lewis numbers are included. Other properties that are characteristic of this type of problem are also calculated.

A library of thermodynamic data in the form of least squares coefficients is provided for over 1,000 ideal gases and condensed species in the temperature range of 300 to 5,000 K. Transport and relaxation data are provided for 59 species, and additional transport data are provided for interactions between unlike species for another 58 interactions. When transport data are missing for a particular interaction, the data are estimated. The estimating techniques are built into the program.

CECTRP can accommodate up to 24 reactants, 20 elements, and 600 products, 400 of which may be condensed. It is written in FORTRAN IV for any large computer system: It is run at NASA Lewis Research Center on an IBM 370 and on a CRAY IS computer. The thermodynamic and transport data are used in an unformatted form. Many DO-loops have been vectorized for class VI computers.

This program was written by Bonnie J. McBride of **Lewis Research Center.** *For further information, Circle 92 on the TSP Request Card.*
LEW-14166

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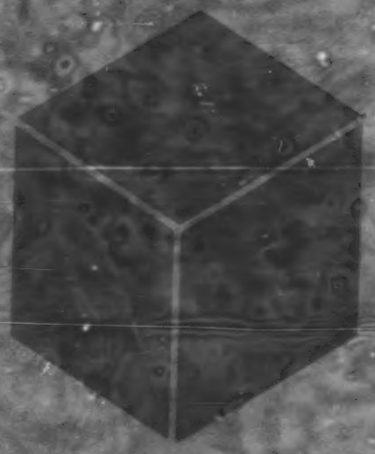
Materials



Hardware, Techniques, and Processes

80 Low-Gravity Alloy Studies on Aircraft
82 Monitoring Prepregs As They Cure
84 Low-Cobalt Powder-Metallurgy Superalloy
85 Making High-Porosity Alloy Spheroids
86 Reducing Sodium Contamination in MOS Devices
86 Pressure-Sensitive Resistor Material
87 Colorless Polyimide Containing Phenoxy-Linked Diamines

Low-Gravity Alloy Studies on Aircraft

Controlled solidification can be continued through many dives.

Marshall Space Flight Center, Alabama

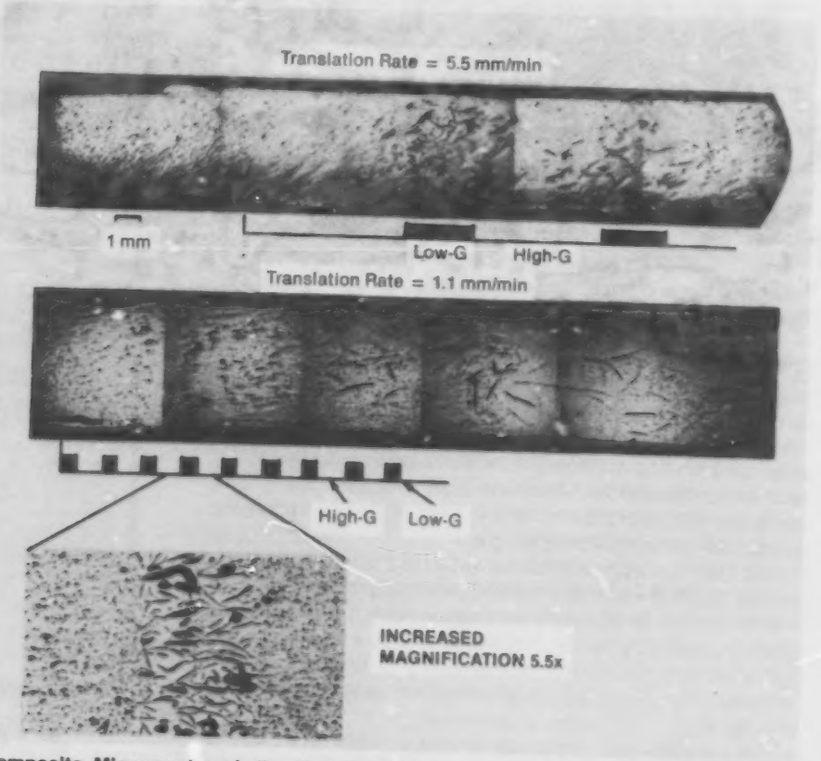
A procedure for directional solidification of alloys under low and high gravity can be carried out aboard aircraft during parabolic arcing flight and pullout from dives. The procedure allows an experiment to be continued over repeated maneuvers. Since each dive gives 20 to 30 seconds in which gravity is 0.001 to 0.1 its normal value, and since an aircraft may make about ten low-gravity maneuvers in a mission, the technique allows substantial time to conduct a low-gravity experiment.

In directional solidification, the liquid/solid interface is advanced slowly through a rod of the sample alloy. The solidification continues during several aircraft maneuvers (see figure). The known solidification rate of the sample can then be correlated with accelerometer data to find the gravity value during solidification for any point in the sample. The thermal gradient and solidification rate are controlled independently.

The process uses a furnace canister containing a resistance heating element on top of a portable quench-block water-circulation system. The sample is placed in a 40-centimeter-long, 1.25-centimeter-diameter vertical alumina crucible, which is encircled by the furnace canister. The furnace is translated along the crucible by a motor and gear train, first melting and then solidifying the sample as it proceeds. The results of a low-gravity experiment on a hypereutectic cast-iron sample suggest that low gravity — and the consequent absence of convection and flotation — promotes the incorporation of large graphite flakes into the solidification front.

This work was done by Peter A. Curreri, Mary H. Johnston, Robert E. Shurney, Wendy S. Alter, D. M. Stefanescu, and J. C. Hendrix of **Marshall Space Flight Center.** *For further information, Circle 26 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 21]. Refer to MFS-25967.



Composite Micrographs of directionally-solidified hypereutectic cast iron show two growth rates. The bands of larger graphite flakes correlated with sample solidified during low-gravity.

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Monitoring Prepregs As They Cure

Quality IR spectra are obtained in a dynamic heating environment.

Langley Research Center, Hampton, Virginia

A new technique obtains quality infrared spectra on graphite-fiber-reinforced, polymeric-matrix-resin prepregs as they cure. An analysis of these spectra provides insight into molecular-level changes in the matrix resin that accompany the processing of prepregs into composites.

This technique resulted from a modification of the diffuse reflectance/Fourier transform infrared (DR/FTIR) technique previously used to analyze environmentally exposed cured graphite composites [see "Resin Characterization in Cured Composite Materials" (LAR-13172) on page 103 of *NASA Tech Briefs*, Vol. 9, No. 1]. The technique should contribute to a better understanding of prepreg chemistry/temperature relationships and to the development of more efficient processing cycles for advanced materials.

Chemical characterization of prepregs, particularly those containing thermoset matrix resins, is generally limited to analyses on neat resins or analyses during the initial stages of prepreg cure. This is because standard tests require the sample to be soluble or transparent. Since cured graphite prepregs or composites are neither, much desirable fundamental information on these materials has been previously inaccessible.

The in situ DR/FTIR experimental arrangement is shown in Figure 1. A small programable-temperature heater was fabricated to replace the sample mount supplied with a commercially available diffuse-reflectance optical accessory. The entire device is placed in the sample compartment of an FTIR spectrometer. The sample can be moved vertically by an adjustment screw operating against spring pressure and horizontally by a sliding mount in the base of the reflectance accessory. Thus, the prepreg sample can be placed in a position at the focal point of the optical system to optimize the signal reaching the detector.

The sample is heated by a ceramic heater controlled by a temperature programer. The programer receives signals from a thermocouple placed between the heater and the silica fiber insulation. A second thermocouple, placed in contact with the prepreg surface, measures the actual sample temperature. The heater can be programed to raise the sample temperature linearly to 750° F (400° C) at rates from 2° to 15° F/min (1.1° to 8.3° C/min).

Isothermal analyses are also possible. Normally, 100 FTIR scans are taken at

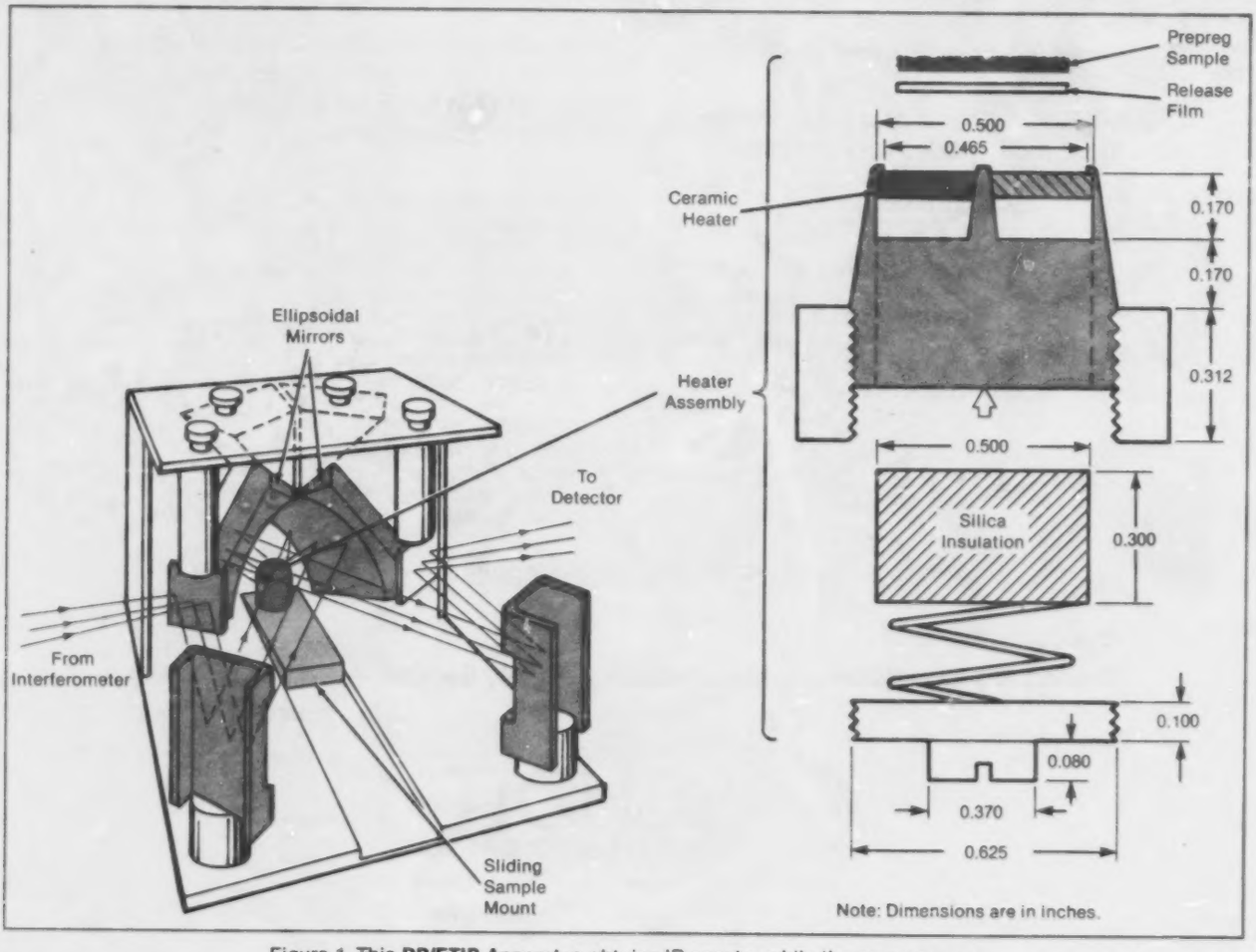

Figure 1. This **DR/FTIR Apparatus** obtains IR spectra while the prepreg cures.

0.5 s/scan and 4 cm^{-1} resolution while the sample is being heated. The scans are then averaged and filed. This procedure is automatically repeated every minute. When an analysis is complete, infrared spectra at any desired temperature interval can be reported. Easily interpretable spectra are obtained.

Figure 2 shows spectra of a graphite fiber/addition-polyimide resin prepreg being heated at 15° F/min. Although many spectra were obtained on this sample, only room temperature, 380° F (193° C), and 615° F (324° C) spectra are shown. Since the graphite fiber makes no contribution to the spectra, all absorption bands are due to the polymeric matrix resin. Changes in the spectra with temperature, which relate to changes in resin molecular structure due to cure, are apparent. For example, amine, ester, and acid groups at room temperature reacted to form imide groups by the time the prepreg had reached 380° F. Further heating caused the resin to crosslink or fully cure as evidenced by the loss of a band at 842 cm^{-1}. An analysis of all spectra obtained on this prepreg could reveal additional details about the cure process.

This in situ DR/FTIR technioue has been used to study numerous prepreg and adhesive systems. Quality spectra on these materials have been obtained for the first time. The information gained is being correlated with other process monitoring techniques such as dielectrometry in an effort to develop more efficient processing parameters for high-performance materials

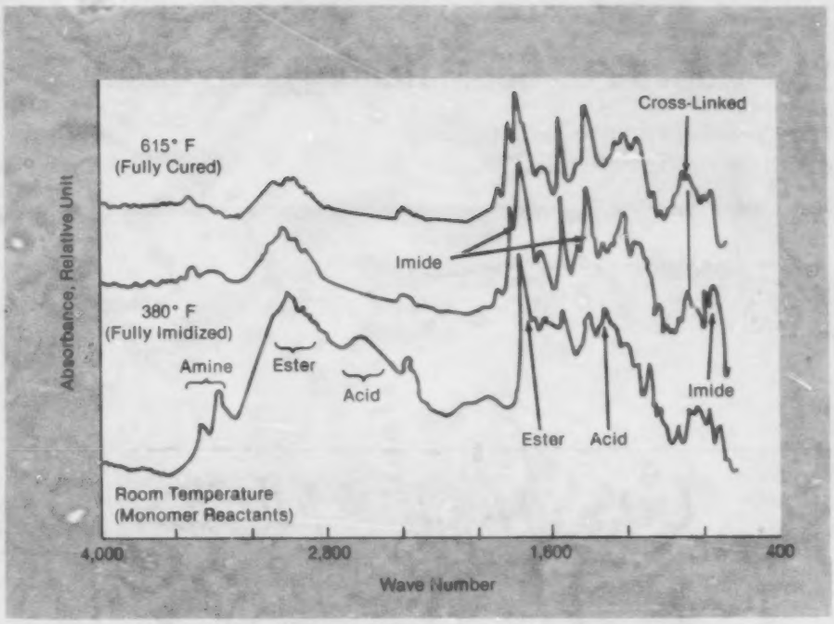

Figure 2. In situ DR/FTIR Spectra of graphite fiber/addition polyimide matrix resin prepreg are shown during cure.

This work was done by Philip R. Young of **Langley Research Center,** *John R. Gleason of the U.S. Army Structures Laboratory, and A. C. Chang of Kentron International, Inc. For further information, Circle 9 on the TSP Request Card.* *LAR-13335*

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Circle Reader Action No. 378

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Highly-stressed jet-engine parts could be made with less cobalt.

Lewis Research Center, Cleveland, Ohio

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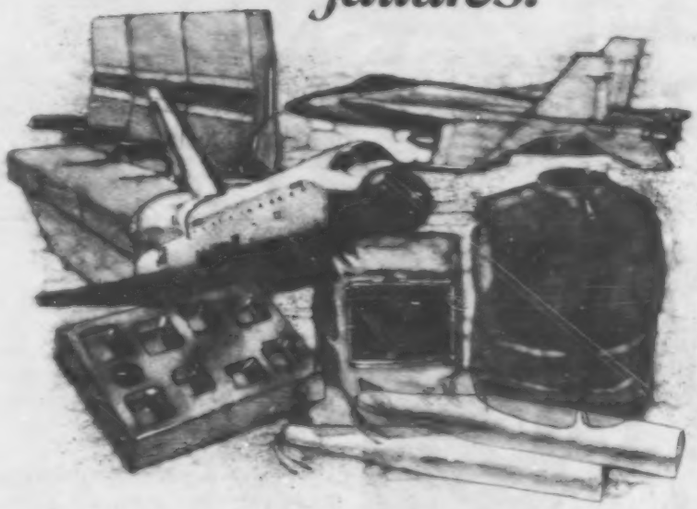

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Circle Reader Action No. 392

Udimet 700* (or equivalent) is a common nickel-based superalloy that has been used in the hot sections of jet engines for many years. This alloy, while normally used in a wrought condition, can also be gas-atomized into a prealloyed powder-metallurgy (PM) product. This product can then be consolidated by hot isostatically pressing (HIP-PM condition) and formed into parts such as a turbine disk. Such jet-engine disks "see" both high stresses and temperatures to 1,400° F (760° C).

Udimet 700* (or equivalent), like most high-temperature alloys, contains several strategic elements. The standard chemistry of Udimet 700* (or equivalent) includes 17 percent cobalt, by weight. Research has been underway at NASA to reduce the consumption of cobalt, one of the most critical strategic materials. The prealloyed powder form of Udimet 700* (or equivalent) was targeted as a possibly modifiable material, which, if successful, would reduce cobalt consumption.

The nominal composition (in weight percent) of the modified alloy is 15 chromium, 8.5 cobalt, 5 molybdenum, 3.5 titanium, 4 aluminum, 0.06 carbon, 0.02 boron, and the balance nickel. This modified chemistry was melted and argon-atomized into powder and packed into steel containers. The containers were sealed by welding in vacuo and hot isostatically pressed at 2,210° F (1,210° C). The alloy was then heat-treated by a partial solution at 2,065° F (1,130° C) and a four-step aging treatment at 1,600° F (870° C), 1,800° F (980° C), 1,200° F (650° C), and 1,400° F (760° C). The microstructure of the heat-treated alloy consists of a gamma matrix (nickel-base solid solution) containing 46 percent gamma prime (alloyed Ni_3Al) particles of three distinct average sizes: 0.5-, 0.2-, and 0.02-μm diameters.

This microstructure is identical with that of HIP-PM Udimet 700* (or equivalent). The modified HIP-PM alloy has an improved creep-rupture life. For example, at 1,200° F (650° C), with a stress of 120,000 psi (825 MPa), failure occurred after an average of 428 hours as compared to 251 hours for HIP-PM Udimet 700* (or equivalent). With a stress of 130,000 psi

(900 MPa), the life doubled to 152 hours, versus 74 hours for HIP-PM Udimet 700* (or equivalent). The advantage persisted at 1,400° F (760° C) where, with a stress of 70,000 psi (475 MPa), the life was 75 hours compared to 60 hours. Minimum creep rates were nearly identical.

Tensile tests at room temperature and at 1,200° F (650° C) and low-cycle fatigue tests at 1,400° F (760° C) showed that the alloy had properties almost equivalent to those of HIP-PM Udimet 700* (or equivalent). These results appear to indicate that a useful substitute exists for standard (high-cobalt) HIP-PM Udimet 700* (or equivalent) and that its use can significantly contribute to conservation of the strategic element cobalt.

(*Udimet is a trademark of Special Metals Corp., New Hartford, New York.)

This work was done by Fredric H. Harf of **Lewis Research Center.** *For further information, Circle 94 on the TSP Request Card.*
LEW-14113.

Making High-Porosity Alloy Spheroids

Noncontact process yields a low-density, porous microstructure.

Marshall Space Flight Center, Alabama

Small spheroids of porous alloys with large surface area per unit volume are produced by a containerless processing method. Without container walls to serve as nucleation sites, an alloy cools to well below its normal freezing point without solidifying. Solidification then proceeds rapidly; the interdendritic liquid is pulled out by the growing crystals, resulting in a porous microstructure. The more rapid the cooling rate, the faster the crystals grow and the more porous the solid becomes.

The process has been used to prepare porous Ni/Al_3 alloy. Powdered Ni/Al_3 was melted in a bell jar over a 100-foot (30-meter) drop tube. The metal at a temperature of 100° to 200° C above melting was forced under gas pressure through an orifice, forming droplets that fell to the bottom of the tube, cooling as they fell. The droplets made no contact with other objects until they struck the bottom of the tube.

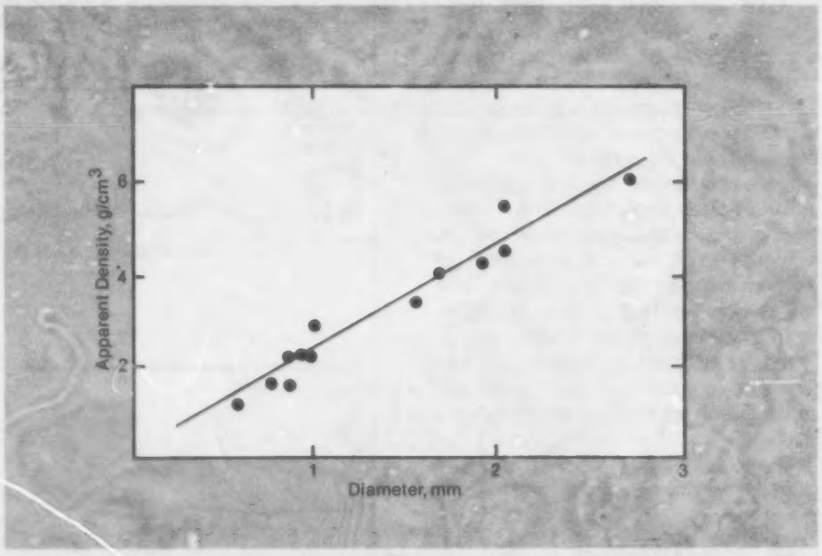
The large droplets did not have enough time to solidify during their fall. They simply splatted on the tube bottom and solidified there. They were much less porous than the small droplets, which solidified completely before reaching the bottom (see figure). The density of the small drops ranged from one-sixth to one-half that of the bulk alloy.

In a related experiment, alloy samples were melted and resolidified while suspended in an electromagnetic levitation apparatus. This method of containerless processing was less successful than the drop-tube method. Specimens were less porous because they could not be cooled as rapidly as in the drop tube.

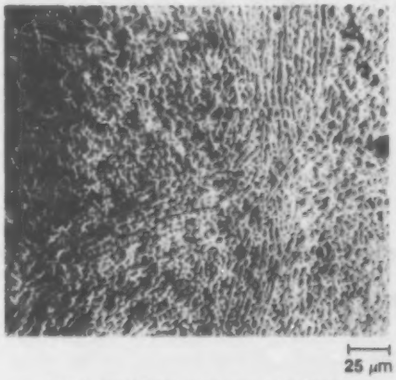
The drop-tube method is likely to be useful in creating porous microstructures from other materials including oxides, carbides, and organic materials. Other means of containerless processing — acoustic or air-jet levitation, low-gravity float melting, melt spinning, or jet spraying, for example — might be adapted to the process. The important conditions for the process are that the material solidify without contact in the absence of strong decelerating and gravitational forces.

This work was done by Edwin C. Ethridge, Peter A. Curreri, and Michael Kelley of **Marshall Space Flight Center.** *For further information, Circle 42 on the TSP Request Card.*

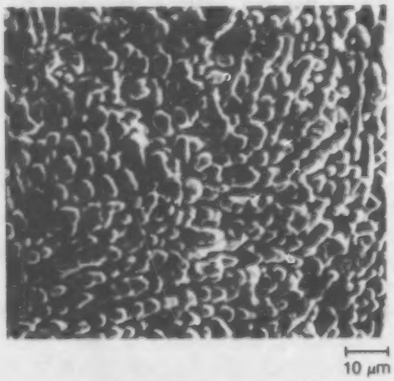
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 21]. Refer to MFS-25997.



Small Drops Are Less Dense and more porous than large ones, as shown on the graph. Below are two examples of porous microstructures.



Ni/Al_3 SPHERE, 0.65 mm DIAMETER DROP-TUBE SOLIDIFICATION



Ni/Al_3 SPHERE, 0.65 mm DIAMETER DROP-TUBE SOLIDIFICATION

Reducing Sodium Contamination in MOS Devices

An electric field would drive positive ions to the surface.

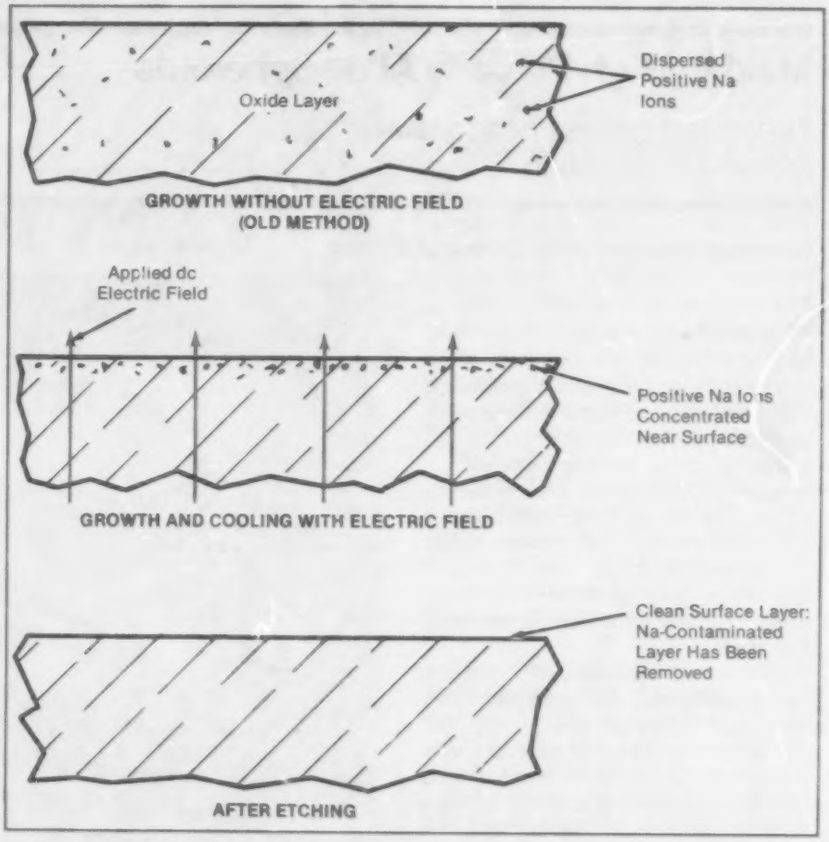
Marshall Space Flight Center, Alabama

A proposed method of removing positive ions from the oxides in metal-oxide-semiconductor (MOS) transistors and integrated circuits would further ensure freedom from contamination by sodium and other mobile positive ions. Such contamination can change the threshold voltage of MOS devices and produce other adverse effects. The new method is intended to supplement established methods of minimizing ion contamination, such as scrupulous cleanliness in processing, purging with hydrogen chloride to react with and remove contaminants, and growing an extra-thick gate oxide, then etching it to remove the large portion of contaminants that are concentrated near the surface.

In the new method (see figure), a steady electric field is applied to silicon wafers while gate oxide layers are grown on them at about 1,000°C and while the wafers cool to room temperature after growth. The wafers would be held in an oxidation carrier boat with their surfaces perpendicular to the electric field. A low dc voltage on plate electrodes at the ends of the boat (or spaced along the boat) would produce the field.

The field would push the positive ions toward the negative electrode, and the ions would move readily in that direction because they are highly mobile in the oxide at the growth temperature. The ions thus gather at the oxide surface and remain there when the wafers have cooled because the ions are no longer so mobile and cannot redisperse at the lower temperature. The standard oxide etch that follows oxide growth thus removes the positive-ion contaminants along with the surface layer of the oxide.

Various other arrangements of the field electrodes are possible. For example, the electrodes could be mounted outside the oxidation furnace tube instead of on the boat.


Oxide Layer
Dispersed Positive Na Ions
GROWTH WITHOUT ELECTRIC FIELD (OLD METHOD)
Applied dc Electric Field
Positive Na Ions Concentrated Near Surface
GROWTH AND COOLING WITH ELECTRIC FIELD
Clean Surface Layer: Na-Contaminated Layer Has Been Removed
AFTER ETCHING

An **Electric Field** is applied during oxide growth to push mobile Na^+ ions to the surface. After cooling from the growth temperature, the field is turned off and the Na^+-contaminated surface layer etched away.

This work was done by Robert F. Dehaye and William R. Feltner of **Marshall Space Flight Center.** *No further documentation is available. MFS-28034*

Pressure-Sensitive Resistor Material

Low-conductivity particles in rubber offer a wide dynamic range.

NASA's Jet Propulsion Laboratory, Pasadena, California

A resistor for which the resistivity decreases smoothly with increasing pressure is a promising candidate as a tactile sensor for robots and remote manipulators. The sensor consists of particles of relatively low conductivity embedded in rubber. The resistance of the sensor decreases by about 100 times as the pressure on it increases from zero to 0.8 MN/m^2.

The embedded particles can be antimony, silicon, magnetite, or nodular graphite. For maximum resistance change, the

particles should be coarse, measuring one-quarter to one-half the thickness of the sensor. They should be uniform in size and shape, angular, hard, and resistant to wear. Compound semiconductors such as PbS, FeS, Fe_3C, and Fe_3P are also promising particle materials.

The rubber matrix should wet the surface of the particles as little as possible, or the resistivity will be too high. Preferably, the rubber should have high tear resistance and low mechanical hysteresis. In the experimental tests of candidate particle materials, room-temperature-vulcanizing silicone and castable urethane were used.

Sieved particles ranging in size from 180 to 250 μm are mixed with uncured silicone rubber in the proportion of 50 percent or more by volume. One part of tin octoate is added as a vulcanizing agent for each 100 parts of silicone and mixed in until the composite has become almost too stiff to be moved. The mixture is spread roughly over a molding plate, and another plate is placed over it. The assembly is squeezed in a vise and allowed to cure. Although the rubber cures enough to permit handling at room temperature in about 45 min, its mechanical properties are best when it is cured for several more hours at 140° F (60° C) after the initial cure and removal from the mold. The resulting rubber layer is about 25 mils (635 μm) thick.

In laboratory tests, nodular graphite, magnetite, and highly doped silicon worked well. The nodular graphite, however, was too coarse to permit sheets less than 50 mils (1.3 mm) thick to be made from it. Crushing the nodular graphite converted it to flake graphite; the flakes tended to aline themselves in the matrix, an arrangement less favorable to conduction than is a random orientation.

This work was done by Eugene R. du Fresne of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 25 on the TSP Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act (42 U.S.C. 2457(f)), to the California Institute of Technology, Pasadena, CA 91125.
NPO-16537

Colorless Polyimide Containing Phenoxy-Linked Diamines

Tough, optically transparent films are produced.

Langley Research Center, Hampton, Virginia

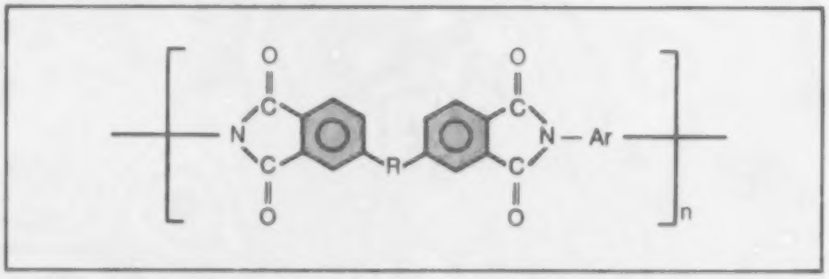
The need exists for high-temperature, flexible polymeric films and coating materials that have high optical transparency in the 300- to 600-nm range of the electromagnetic spectrum for use on antennas, solar cells, and thermal-control coatings. Because of their inherent toughness, flexibility, low density, remarkable thermal stability, radiation resistance, and mechanical strength, linear aromatic condensation polyimide films have excellent potential. However, these films are known for their bright yellow color. Depending on thickness, commercial aromatic polyimide film was found to be only about 70 percent transparent at the 500-nm solar wavelength of interest. Further, the transparency upon aging drops to as low as 30 percent.

A process for preparing aromatic condensation polyimide films containing phenoxy-linked diamine monomers produces films that are essentially colorless. The process involves two conditions:

- purification of both aromatic diamine and aromatic dianhydride monomers and the solvent used as a medium and
- separation of chromaphoric centers and reduction of both inter- and intrachain electronic interactions, which cause absorption in the ultraviolet-to-visible region by introducing phenoxy or thiophenyl "separator" groups and isomeric (m,m′- or o,p′-oriented) diamines into the polymer molecular structure.

Both conditions must be satisfied to produce polyimide films with maximum optical transparency.

In the process, a highly-purified aromatic diamine is dissolved in a distilled amide-type solvent such as dimethyl acetamide. A highly purified dianhydride is then added to the diamine solution at room temperature to form a polyamic acid. This resin is then spread onto a glass plate to form a film, using a doctor blade with a specified blade gap. The polyamic acid film is then thermally converted, by heating to 300° C, to an optically-transparent polyimide film housing the molecular structure shown in the figure. All of the highly optically-transparent polyimide films produced have meta-or o,p′-oriented aromatic diamines and phenoxy groups in their molecular structures. The use of highly purified monomers containing oxygen-linked phenoxy groups and o,p′- or m,m′-orientation in the diamine proved successful for reducing chromaphoric centers, conjugation, and overall charge-transfer-complex formation in the polymer.



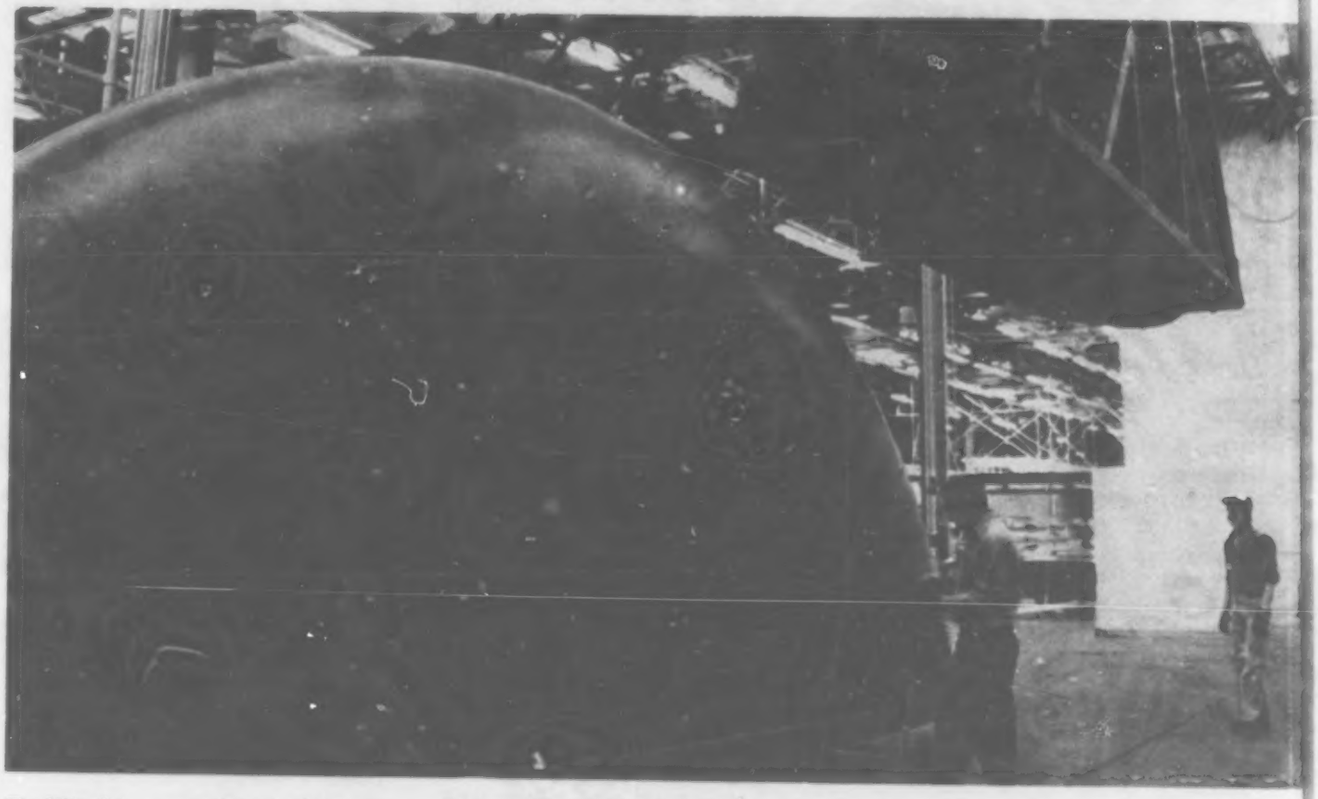
Polyimides Having This Molecular Structure form tough, transparent films. The films are made transparent by careful control of manufacturing conditions, including the use of highly purified monomers.

The films obtained have 90-percent transparency at the visible wavelength of 500 nm, compared with 60- to 70-percent transparency for commercial polyimide film of the same thickness. It is anticipated that these optically transparent/achromatic films will prove highly useful as film and coating materials for aerospace and other applications where high transparency and thermal stability are necessary properties. This improvement in transparency has been made at no sacrifice in thermal stability, flexibility, toughness, or mechanical properties of the polymer.

This work was done by Anne K. St. Clair and Terry L. St. Clair of **Langley Research Center.** *For further information, Circle 98 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 21]. Refer to LAR-13353.

Introducing a revolutionary new composite materials tooling system



ToolRite® is a complete tooling materials system that uses low cure temperature prepregs formulated exclusively for tooling. Compared with conventional wet lay-up, it is faster, cleaner, and easier to handle. Tool life is 500% longer. And, being a prepreg system, it assures uniform resin distribution, virtually free of voids and pockets, so thermal cycling has less effect. Heat distributes evenly. Warping is 70% less.

Compared to metal tooling, the ToolRite System provides exceptional dimensional accuracy and thermal stability. Tools and parts heat up and cool down together, at the same rate. Damage and distortion are practically eliminated. Parts come off the tool faster, too.

And because of lower mass, the ToolRite System saves energy—whether you cure by vacuum bag or autoclave.

The ToolRite System cures completely on a master model at 200° to 210°F. It can be removed from the master and post-cured, free-standing, at 350° to 375°F—with service temperatures of more than 400°F.

ToolRite is no ivory tower idea fresh from the drawing board. It is already in use in more than 2,000 tools throughout the aerospace industry worldwide. Here is how two of these users are benefiting from the unique properties of the Fiberite ToolRite System.

Shell lay-up time on the AWACS radome tool was cut an estimated 40% due to fewer plies of thicker, more easily applied material.

One of the world's largest high temperature fiberglass/epoxy tools, the AWACS radome lay-up mandrel is 12½ ft. high, 5½ ft. wide and 30 ft. long at the base. In the past,

ToolRite,® from Fiberite

with wet lay-up, Boeing fabricated the mandrel in two sections and cured each half separately. Thus, there were three cure cycles–Left, Right, and Spliced. With the ToolRite System, as specified by Boeing, the halves can be laid up *and spliced*, then cured in a single cycle. This saves four cycles when building the pair of mandrels required.

Large size and close dimensional tolerance make such a tool expensive to fabricate. But, with the ToolRite System, Boeing has been using the tool for three years and still does not see the end of its useful life. Also, compared with previous tooling, labor for tooling rework to retain vacuum integrity has been cut more than 90%.

As a result of the change from wet lay-up to the ToolRite System, physical properties of the tool have improved greatly. Flexural strength at 350°F is nearly twice that of the previous systems.

"To date, we have over 500 cycles on some of our prepreg tools with no indication of leakage or thermal shock cracks."
R.T. Williams, Manager
Composites and Bonded Structures
Teledyne/Ryan Aeronautical

Ray Williams knows prepreg tooling. He has more than 700 ToolRite tools in inventory at Teledyne/Ryan.

"If you're building graphite, aramid or glass parts, you must match the thermal characteristics of the tool with the part," Williams says. "With interlocking curvatures, projections and tight radii, the tool and the part must expand and contract at the same rate, or you lose dimension."

Uniform resin distribution is important, according to Williams, because resin-rich areas act as a heat sink subject to thermal shock, resulting in premature tool failure. "Using graphite prepreg, we project the life of our tools somewhere near 750 cycles. In addition, the tools are light, and easy to handle and store."

Designing with the ToolRite System has significant advantages over traditional design, according to Williams. "Designing one structure of composite tooling, we've

Is it possible to make an asymmetric part with composite tooling? Using the ToolRite System, Teledyne/Ryan Aeronautical designed this split graphite tool used to fabricate an engine intake duct for the AH-64 attack helicopter. Harbor Patterns, Inc., Los Alamitos, CA, built the tool.

been able to totally design out 11 different components. By eliminating part count and secondary operations, you can really begin to save money," he says.

You can get details on the ToolRite Prepreg System for composite tooling–and arrange a technical briefing for your management and an in-shop

Add Beech Aircraft to the growing list of ToolRite System users, which already includes Boeing, MBB, CASA (AirBus), BAe, Dassault and Teledyne Ryan. The upper and lower wing skin tools for the Beech Starship I (above) were fabricated using this revolutionary new prepreg tooling system for composite parts.

demonstration–just by picking up your phone. Call Clint Juhl or Kris Ralph at (714) 639-2050, and describe your project. Or use the coupon below.

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Books & Reports

Self-Contained Neutral-Buoyancy Suit

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Self-Contained Neutral-Buoyancy Suit

A "dry suit" would add to the realism of zero-gravity simulations.

A report discusses a self-contained diving suit to be used in simulations of zero-gravity maneuvers in a space suit. The method, called neutral-buoyancy immersion, is useful in preparing astronauts for extravehicular activity.

In neutral-buoyancy immersion, a person clad in a modified space suit enters a water tank. Weights are attached to the suit until the wearer has balanced neutral buoyancy—that is, in the absence of body movement, the subject does not rise, sink, or rotate, but simply floats under the surface. The person then trains for space walks by maneuvering the body, learning tasks, and generally getting used to weightlessness.

The disadvantages of the present neutral-buoyancy techniques are due to an umbilical cord. Breathing air, cooling, ventilation, and communication are all supplied through this cord. In real space walks, however, astronauts carry self-contained life-support equipment in backpacks. The umbilical cord therefore detracts from reality. The test subjects, for example, cannot start a training session from an air lock with a closed hatch, as a space walk would start. The umbilical cord also tends to become ensnarled in equipment, creating twisting, turning, and pulling forces on the wearer that do not occur in space.

The report recommends that a commercial "dry suit" used in self-contained underwater diving be modified to replace the space suit with its umbilical cord. The new suit should be equipped with a life-support backpack, including wireless acoustic-carrier voice communication. To feel like a space suit, the modified suit would include such key space-suit accessories as gloves, boots, helmet, and visor.

Tests on a modified dry suit showed that the concept is feasible. The report analyzes the requirements for a suit designed expressly for neutral-buoyancy immersion. Many parts of the suit are already available or could be fabricated readily with minimal development.

The report concludes that the proposed suit would closely approximate the sensation of zero gravity. The self-contained air supply, communication, and cooling would allow spaceflightlike flexibility of movement. The turnaround time between uses is only 2 hours, as opposed to 48 hours for the conventional space suit. Only four technicians would be needed to prepare the suit and assist the wearer in neutral-buoyancy tests; a conventional space suit needs many more technicians.

This work was done by Barry E. Boswell, Bilby J. Wallace, and Thomas G. Woods of McDonnell Douglas Corp. for **Johnson Space Center.** *To obtain a copy of the report, "Manned Simulation of Zero-g Utilizing Neutral Buoyancy," Circle 20 on the TSP Request Card.*
MSC-20424

Capture the Glory!

Now you can own this collector's print, commemorating Columbia's exploits, at an exceptional introductory price.

Noted aviation artist Ken Kotik has captured *Columbia* in all its glory to commemorate the completion of four test flights and the first operational mission, STS-5. This fine print—truly a collector's item—depicts the orbiter in full color, side view, with every feature crisply detailed.

Arranged beneath the ship, also in full color, are the five distinctive mission patches. But what makes Ken Kotik's work most unique is his method of creating a 'historical panorama' via individual vignettes surrounding the side view of *Columbia*.

Educational as well as eye-appealing, these scenes, which are expertly rendered in a wash technique, include such subjects as the orbiter under construction at Rockwell, on the launch pad, at touch-down and during transit on its 747 carrier. Concise copy, hand-written by the artist, accompanies each vignette. (*Important:* The greatly reduced print reproduced here is intended only to show style—at the full 32" by 24" size, all copy is clearly readable.)

About the artist.

Ken Kotik, a 37-year old Colorado native, has been a professional commercial artist for the past 14 years. In his own words, he "eats, drinks and sleeps flying." It shows in the obvious care and attention he brings to each print or mural. When not at his drawing board creating artworks for such prestigious institutions as the Air Force Academy, Ken can be found at the controls of his Schweitzer sailplane, in which he competes nationally. A self-taught artist, he specializes in airbrush-applied acrylic techniques. *Space Shuttle Columbia: The Pathfinder* is his first work on the space program, and the original art has been accepted by the Smithsonian Air and Space Museum for its permanent collection.

About the artwork.

Space Shuttle Columbia: The Pathfinder was printed in five colors, after individual press proving, on exhibit-quality 80 lb text 'Hopper Feltweave' textured paper. The feltweave texture yields properties most desirable for framing and display.

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Mechanics

Hardware, Techniques, and Processes

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94 Self-Aligning End Supports for Energy Absorber
94 Combined Devices for Turbulent-Drag Reduction
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Cradles for Support in Transit

C-shaped cradles distribute weight of large objects.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed system of cradles would support loads of a wide range of weight, shapes, and sizes for transportation. Originally developed for holding a satellite in the bay of the Space Shuttle orbiter, the concept is also adaptable to such terrestrial uses as carrying odd-shaped equipment by truck.

A cradle set would consist of a single prime cradle and several basic cradles. Composed of a bar bent into a half circle, each cradle would have its own keel and

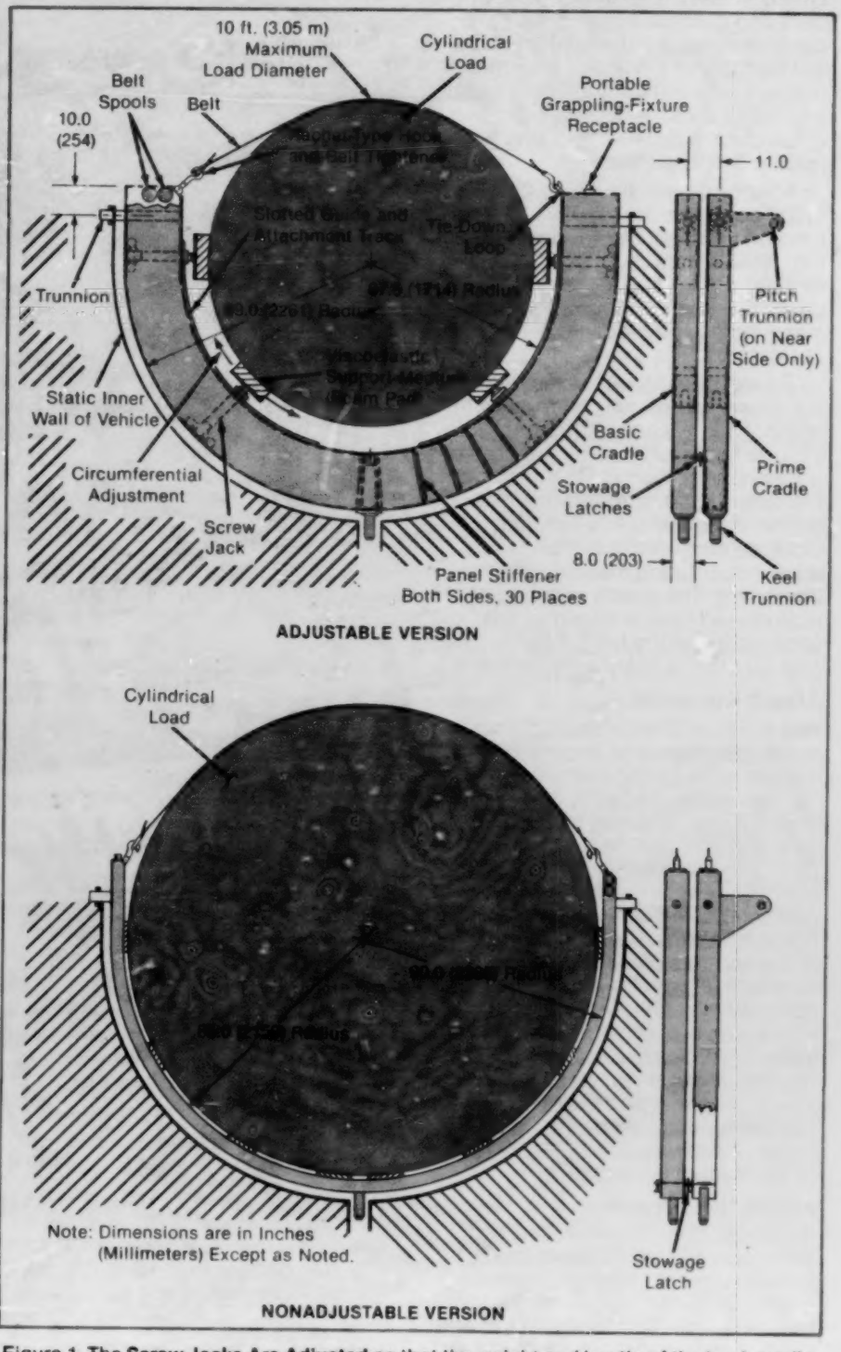


Figure 1. The **Screw Jacks Are Adjusted** so that the weight and inertia of the load are distributed fairly evenly to all the foam pads.

longeron trunnions that brace the structure by mating with receptacles in the vehicle and its own foam pads, on which the load rests (see figure). One 548-lb (249-kg) cradle would support up to 3,000 lb (1,361 kg); thus, a 15,000-lb (6,800-kg) object would require five cradles distributed along its length. Through their trunnions, the cradles would spread the weight of the load along the vehicle.

As shown at the top of Figure 1, the elastomeric pads could be mounted on screw-jack struts that can be moved in a radial direction. The positions of the pads could therefore be adjusted so that they bear against an irregularly shaped load. A non-adjustable version for large, regular cylindrical loads is shown at the bottom of Figure 1.

For storage, the cradles could be removed from the vehicle or stacked together at one end of the vehicle, as in Figure 2. A stowage latch on each cradle would secure it to its neighbor. A receptacle on each cradle would allow it to be handled by a remote manipulator for storage and deployment.

This work was done by W.H. Crane and H.T. Fisher of Lockheed Missiles & Space Co., Inc., for **Johnson Space Center.** *No further documentation is available.*
MSC-20725

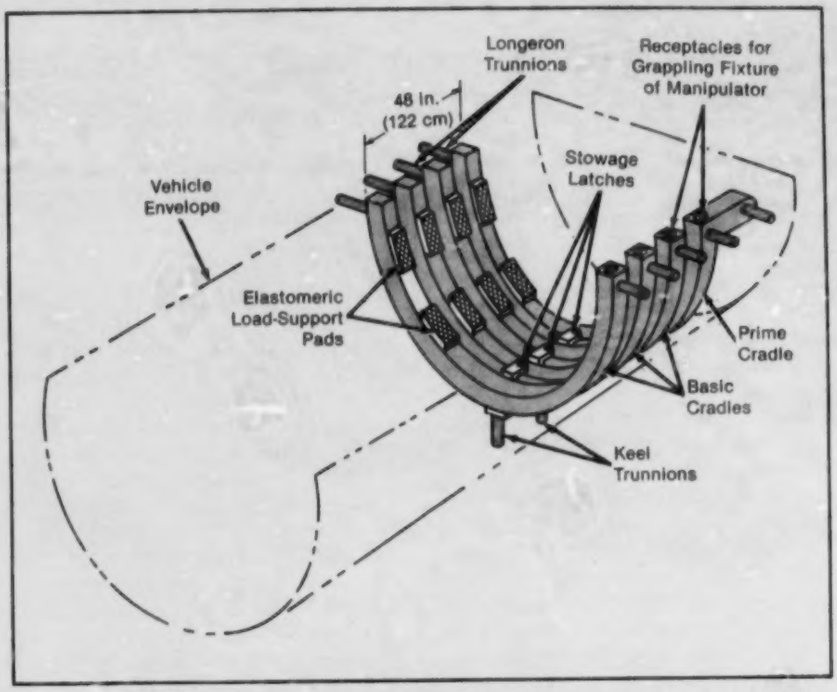


Figure 2. **When Not in Use, Transport Cradles Nest Together** as shown here. For deployment, they are separated and spaced evenly in the vehicle (here indicated in outline). The prime cradle differs from the basic cradles in that it has an additional longeron fitting to resist pitching movement.

Internally Wrenching Nut

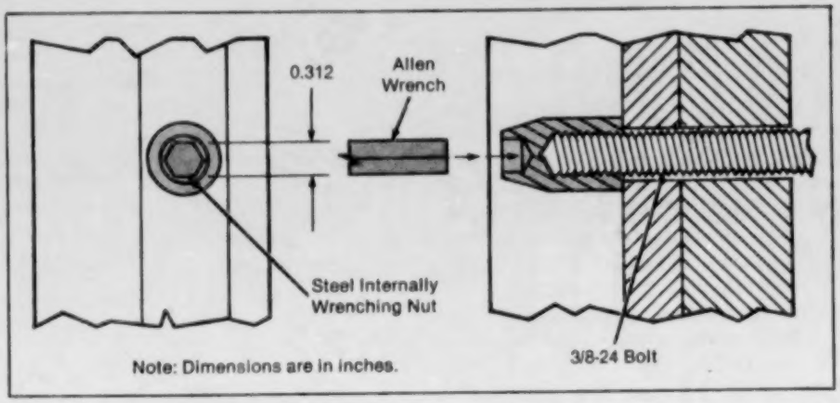
Less space is needed for installation and removal.

Marshall Space Flight Center, Alabama

A nut for use with short bolts is torqued with an allen wrench (see figure). In contrast with standard hexagonal nuts, the new nut requires no external wrench clearance on the installation surface.

As with allen-head bolts, the nut can be held on the wrench temporarily by gravity, friction, or a sticky material and can be carried to the installation point through a narrow otherwise-inaccessible space. The new nut should have many uses in assemblies where space is limited, especially in the automotive and aircraft industries.

This work was done by Reuben G. Cortes of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29068



The **Internally Wrenching Nut** has a hexagonal wrenching hole like that of an allen-head bolt. It is installed or removed with an ordinary allen wrench. Although the bolt shown here has a 3/8-inch-24-thread, the concept is applicable to other thread sizes.

Self-Alining End Supports for Energy Absorber

Simple devices stabilize axially-loaded compressive members.

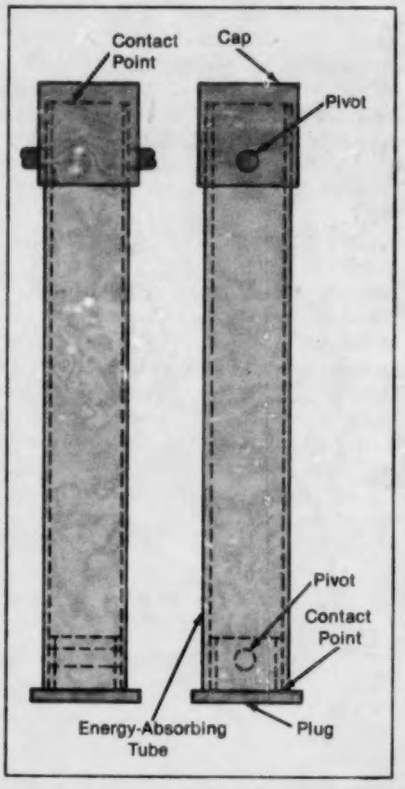
Langley Research Center, Hampton, Virginia

A method has been developed to stabilize the axial compressive loading of an energy absorber by the use of end supports (cap and plug) that pivot to compensate for off-axis loading. Previously, off-axis loading of only a few degrees could cause excessive bending, instability, or failure of the energy-absorbing device. The self-alining supports described here are small, lightweight, and almost maintenance-free. Their use eliminates the alinement problem, opening up more applications and providing higher reliability for compressively-loaded energy absorbers.

The energy absorber is held by two end supports: an upper cap and a lower plug (see figure). The upper cap pivots below the contact point between the cap and the energy absorber. The load is transferred from the structure to the pivot, to the cap, to the energy absorber. It is essential that the pivot be located below the contact point between the cap and energy-absorber tube for loading stability. The same applies to the functioning and location of the pivot in the lower plug. The use of a cap-and-plug combination controls the direction of crushing, which in this case starts at the cap end and progresses toward the plug end.

The tube can be designed to crush at either end. The device alines both ends of the tube to keep the force vector along the axis of the tube. The device is self-alining and simulates physically a movable fixed-end condition. Column buckling of the tube is not a problem because such a tube is designed to crush at a load below the Euler buckling load. Furthermore, as the tube crushes, it gets shorter, thereby making buckling even less likely. The device may be particularly useful to designers working with composite tubes that, in crushing, act as brittle material and are difficult to control.

This work was done by Emilio Alfaro-Bou and Charles P. Eichelberger of **Langley Research Center** *and Edwin Fasanella of Kentron International, Inc. No further documentation is available.*
LAR-13295



The **Energy-Absorbing Column** is held by two end supports, which stabilize the column and tolerate misalinement. The column absorbs an excess load by collapsing lengthwise.

Combined Devices for Turbulent-Drag Reduction

Aircraft skin-friction drag can be reduced as much as 15 percent.

Langley Research Center, Hampton, Virginia

Energy conservation has been a driving force behind research into methods that can reduce the turbulent skin-friction drag on transport-aircraft fuselages. Reductions in fuselage skin-friction as small as 10 percent could potentially save $250 million per year in fuel costs for the commercial airlines.

One effective drag-reduction technique involves the use of riblets. Riblets (see Figure 1) are longitudinal striations or grooves that are machined on an originally smooth surface. The grooves are alined with the flow. The grooves have depths and spacings on the order of the turbulent wall-streak and burst dimensions

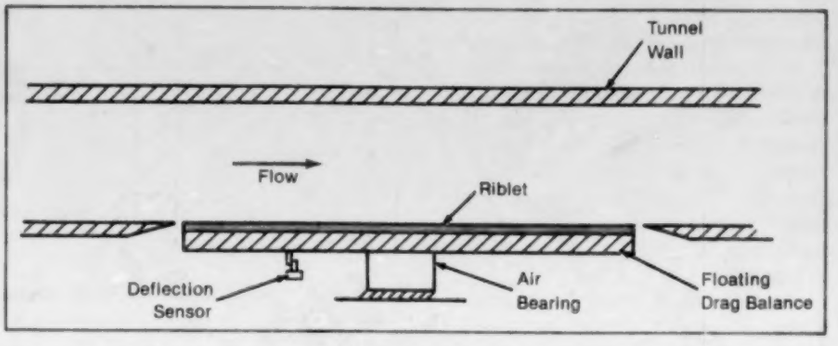


Figure 1. A **Riblet,** shown here in a wind-tunnel-test configuration, operates on the near-wall structure of a turbulent boundary layer.

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Circle Reader Action No. 412

and are designed to change the near-wall structure of the turbulent boundary layer. Properly optimized, the grooves reduce the net drag by 8 to 10 percent.

Another approach, using large-eddy-breakup (LEBU) devices, or turbulence manipulators or ribbons as they are sometimes called, has also demonstrated reductions in local skin friction and net drag in air for some laboratory conditions. The LEBU device (see Figure 2) consists of thin, ribbonlike strips or airfoils suspended parallel to the test surface and positioned within the turbulent boundary layer. A properly optimized LEBU configuration has been shown to reduce the net drag by 7 percent.

The present technique involves the combination of the two Langley-developed individual drag-reduction concepts: riblets and LEBU's. Since the riblets are designed to operate on the near-wall structure of the turbulent boundary layer and the LEBU devices are designed to operate on the large-scale outer structure and only indirectly on the wall structure, it is not evident that the drag-reduction performance of the riblet and LEBU would be additive. However, tests conducted at Langley on a combined riblet and LEBU configuration have shown that the drag-reduction performances of the two devices are, in fact, approximately additive.

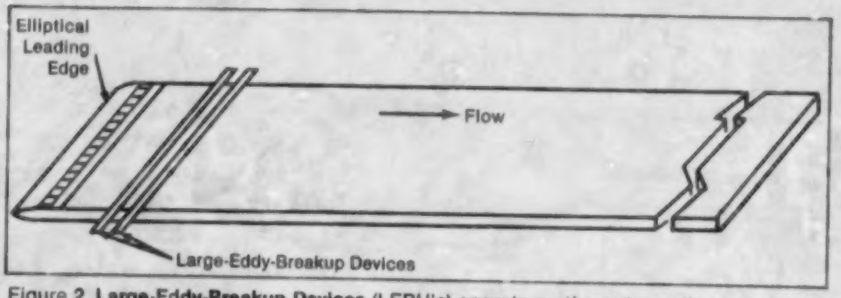


Figure 2. Large-Eddy-Breakup Devices (LEBU's) operate on the outer-wall structure of a turbulent boundary layer. Here, two LEBU's are shown on a test plate.

The combined technique can potentially reduce the net skin-friction drag by at least 15 percent on the turbulent boundary layer of an aircraft, representing a possible annual saving in fuel costs of $300 to $400 million for the U.S. commercial fleet. This technique could also be applicable to friction-loss reduction inside pipes and ducts, contributing to the increased efficiency of pumps, heat exchangers, air conditioners, and other devices involving fluid flow.

This work was done by Michael J. Walsh, John B. Anders, Jr., and Jerry N. Hefner of **Langley Research Center.** *For further information, Circle 96 on the TSP Request Card.*

This invention is owned by NASA and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 21]. Refer to LAR-13286.

Clip-On Extensometer

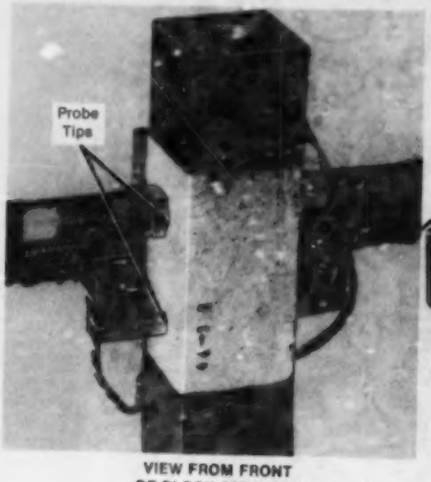
A flexural clamp eliminates problems of operator variability.

Lyndon B. Johnson Space Center, Houston, Texas

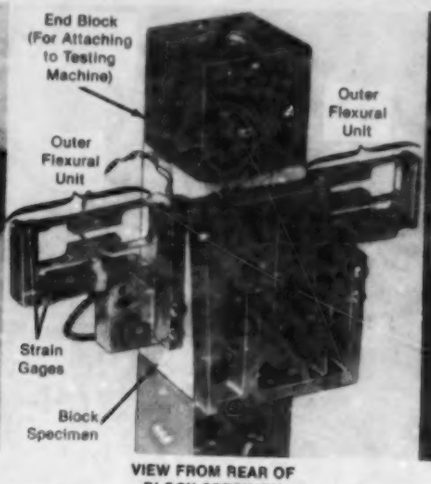
A clip-on extensometer developed for testing Space Shuttle insulation tiles accurately measures length changes of loaded specimens. The new design reduces measurement errors caused by variability among test operators.

The extensometer is intended for use on ceramic, metal, or polymeric specimens (see figure). It consists of three flexural units. The central unit serves as a spacer, and the outer two units clamp on the specimen.

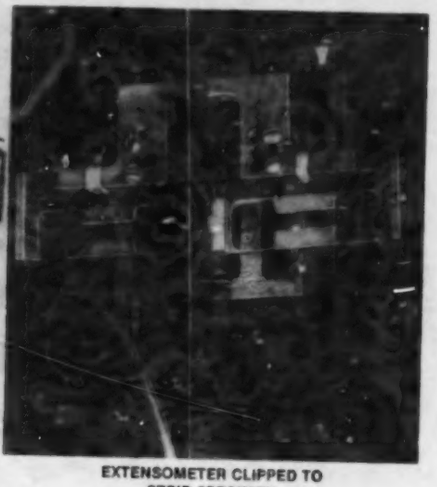
The operator attaches the extensometer to a specimen by squeezing together two screws on the central flexure unit. This moves the outer units apart so that the extensometer can be slipped over the specimen. When the operator releases the



VIEW FROM FRONT OF BLOCK SPECIMEN



VIEW FROM REAR OF BLOCK SPECIMEN



EXTENSOMETER CLIPPED TO STRIP SPECIMEN

The Extensometer Opens and Closes Like a Clothespin and can thus be placed easily on a specimen. The dimensions of the block specimen are 1 by 1 by 2.2 inches (2.54 by 2.54 by 5.59 centimeters). By constructing central flexure units of various widths, one can adapt the extensometer to handle specimens ranging from thin strips to those many inches thick.

screws, the outer units move toward each other, pressing on the specimen sides with a force of 1.2 pounds (5.3 N). Each outer unit contacts the specimen with two small probe tips on flexing arms that are instrumented with strain gages.

As a tensile or compressive load is applied to the specimen, the corresponding change in specimen length is transmitted to the strain gages. Each gage is previously calibrated separately, and an appropriate amount of resistance is added to the gage producing the highest output; each gage thus ends up with the same sensitivity. The two outputs are summed to give an average strain value.

Previously, a strain-gage fixture had to be installed on the specimen by alternately tightening the screws in each of a pair of plates to embed sensing tips. The amount of tightening varied among operators and created uncertainty about the distance between the tip and the strain gage. Now, with the clothespin extensometer, strain measurements are repeatable within 1 percent for a test-machine stroke of 0.005 in. (0.127 mm).

This work was done by Alan M. C. Holmes and Michael C. Duggan of Lockheed Missiles & Space Co., Inc., for **Johnson Space Center.** *For further information, Circle 21 on the TSP Request Card.*
MSC-20710

Precise-Conductance Valve Insert

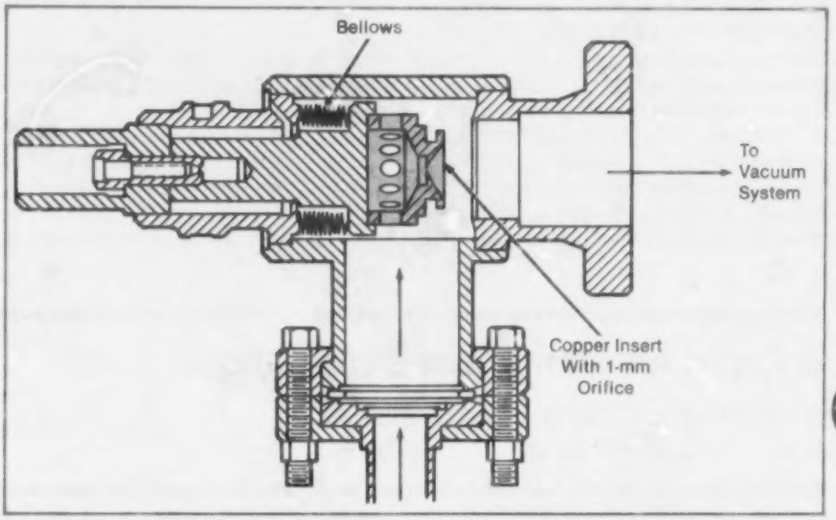
A valve modification provides two operating modes: fully open and small, precise leak.

Langley Research Center, Hampton, Virginia

Numerous applications in surface physics, vacuum physics, materials science, gas kinetics, thin films, and other areas of research require measured flows of gas into or out of systems. This is generally accomplished by use of the calibrated leaks, permeation membranes, or small precision apertures. All of these techniques involve paths of small or virtually zero conductance, but it is often desirable to be able to increase the conductance back to some large level for such other system operations as purging or bakeout of the upstream region. In the past, these fixed conductances were just accepted limitations of the systems, and it was necessary to include alternate high-conductance paths with additional valves, couplings, gaging, and other expensive vacuum hardware.

By replacement of the ordinary copper valve seat in a commercial all-metal-seal, right-angle valve with an inexpensive insert, a high conductance becomes available in the fully open position, which facilitates ultra-high vacuum (UHV) cleanup or other system operations. In the closed position, this insert permits a calculable small conductance to provide a metered flow rate into one of the two regions separated by the valve. The figure shows the insert mounted in a 1.375-in. (34.92-mm) inside-diameter, commercially-available right-angle valve in the open configuration.

The insert is thicker than an ordinary valve seat and is bored out to a diameter of 0.75 in. (19.05 mm) with 10 evenly spaced and radially oriented holes of 0.187-in. (4.75-mm) diameter and 0.2385-in. (6.06-mm) length. The conductance of the small aperture at the apex of the machined cone is 0.088 l/s (N_2), which is at least 100 times smaller than the valve conductance on either side, thus giving a precise effusion rate for a given upstream pressure.



The Copper Insert With Radially Oriented Holes allows a small, controllable, precise effusion rate when the valve is closed or nearly unobstructed flow when the valve is open.

The cone can be machined in either direction to establish desired effusion conditions. Different conductances can be effected by controlling the size of this aperture; a range from 10^{-4} to 1 l/s for this size valve is possible. The upper limit for larger valves is approximately 40 l/s.

These inserts can also be made into permeation membranes of palladium or silver for metered flows of H_2 and O_2, respectively. The conductance of the valve illustrated in the open position is approximately 25 l/s (N_2), which is sufficient for normal operation. When the valve is closed, the conductance is reduced to a precise 0.088 l/s (N_2). The lifetime of the device is essentially the same as for the normal copper seat (>50 closures).

The insert is easily machinable and can be inserted into an existing commercial all-metal-seal UHV valve in place of the standard seat. The desired conductance may be obtained by machining or by using a membrane to provide a calculable flux from permeation. In the fully open position, valve flow and system operation are normal for that valve. In the closed position, the valve flow becomes a precision leak. This device has been successfully proved over several years in a wide range of applications, including secondary standards, gage-calibration-orifice systems, gas-adsorption devices, and other experimental systems.

This work was done by Ronald A. Outlaw and Ronald F. Hoyt of **Langley Research Center.** *For further information, Circle 86 on the TSP Request Card.*
LAR-13340

Detecting Cavitation Pitting Without Disassembly

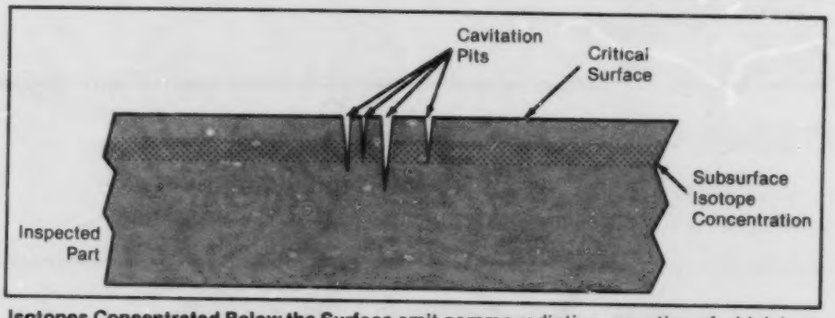
A new method is based on isotope generation in the inspected part.

Marshall Space Flight Center, Alabama

A technique for detecting cavitation pitting in pumps, turbines, and other machinery uses low-level nuclear irradiation. It is important to detect cavitation pits because a nozzle, turbine blade, or other pump component weakened by cavitation could fail catastrophically and cause the machine to explode.

Until now, such pitting could be detected only by disassembling the machine and checking parts visually for damage. This procedure is costly in time and labor.

In the new method, the surface to be inspected is irradiated with protons or alpha particles from small particle-beam accelerators in such a way that most of the isotopes generated by the particle beam are concentrated inside the part, within a few thousandths of an inch (within about 0.05 mm) of the surface. Though the radiation is applied from within the machine housing, the residual low-energy gamma radiation from the part is measured from outside the housing. To obtain the spatial resolution needed to detect the pits, lead or tungsten shielding is placed around the detector line of sight.



Isotopes Concentrated Below the Surface emit gamma radiation, a portion of which is attenuated by the overlying material. Where there are cavitation pits, the output of a gamma-ray detector fluctuates as the detector is scanned near the pits.

If only slight surface erosion has occurred, no significant change in radiation level is measured. However, if cavitation has created sharp pits (see figure), the radiation level fluctuates significantly while scanning the gamma detector near the pits. Maintenance people can then be alerted to change the part.

This work was done by S. Barkhoudarian of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-19902

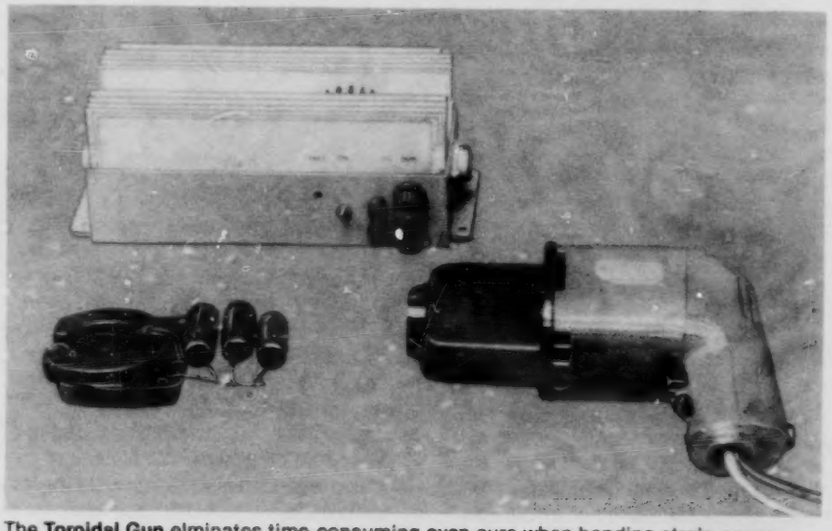
A Rapid Attachment of Strain Gages

A hand-held toroidal gun concentrates heat in a localized area.

Langley Research Center, Hampton, Virginia

A new method for bonding film gages (e.g., strain gages) eliminates time-consuming oven curing. A hand-held "gun," (see figure) operates on induction heating to concentrate heat in a localized area. A ferritic plate is added for low-reluctance or no-reluctance surfaces.

The method reduces adhesive cure time from hours to minutes. It is primarily applicable to the bonding of strain gages at about 204° C. If the surface is a ferritic material such as 410 stainless steel, sufficient heat to cure an adhesive is generated within the steel because of reluctance and poor thermal conductivity. If the bonding surface is nonferritic, however, a ferritic material in the form of a thin plate [1/8 in. (3.2 mm)] with a thin rubber pad is placed between the specimen and the energy source. Adequate heat is conducted and radiated from the ferritic plate



The **Toroidal Gun** elminates time-consuming oven cure when bonding strain gages.

to cure a bonding adhesive. In bonding a film gage, the gun is placed on the gage with approximately 5 pounds of pressure per square inch (3.4×10^4 N/m^2) and energized for 2 minutes. Pressure is maintained for an additional minute during cooldown.

The lightweight, portable gun is a fast, low-power device. Bonding results indicate that, by heating the surface material itself, no internal heating of the strain-gage grid (which may cause strain-gage damage) takes place during bonding.

This work was done by Timothy D. Schott, Robert L. Fox, and John D. Buckley of **Langley Research Center.** *For further information, Circle 11 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 21]. Refer to LAR-13237.

Easily Accessible Camera Mount

The mount reduces installation time and holds the cameras more securely.

John F. Kennedy Space Center, Florida

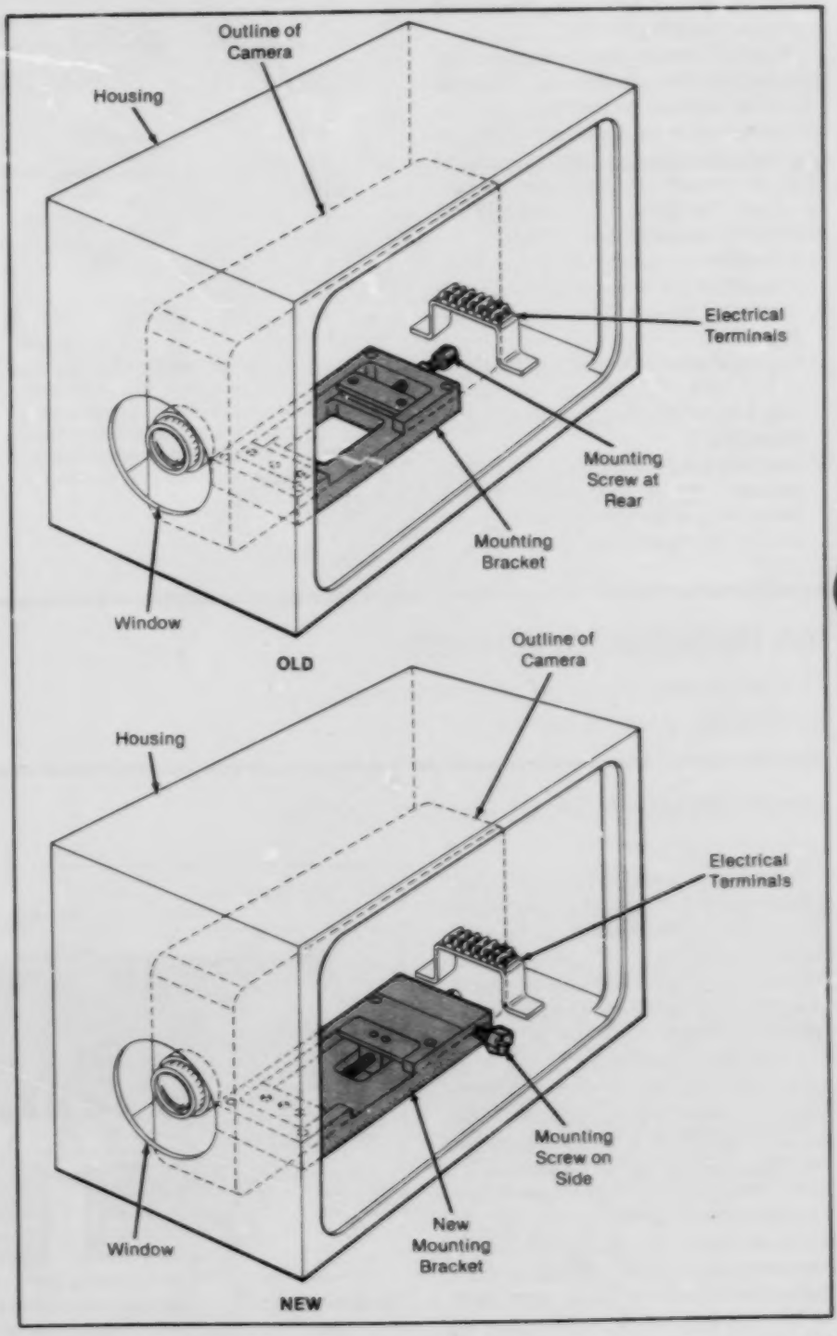
A modified mount enables fast alinement of movie cameras in explosionproof housings. The previous mount had a knurled, slotted head screw at its aft end. When a camera was mounted, there was little room between the camera and the housing for the installer's fingers to tighten the screw to secure the camera. Often, the camera would come loose from vibrations and produce blurred images.

With the modified mount, the screw is on the side and is readily reached through the side door of the housing (see figure). The mount includes a right-angle drive mechanism containing two miter gears that turn a threaded shaft. The shaft drives a movable dovetail clamping jaw that engages the fixed dovetail plate on the camera. The mechanism thus alines the camera in the housing and secures it.

The mechanism reduces installation time by 80 percent. The time saved is significant when many cameras are set up to record an event.

This work was done by Howard E. Chalson of PRC Systems Services for **Kennedy Space Center.** *For further information, Circle 47 on the TSP Request Card.*

KSC-11316



A Camera-Securing Screw is easily reached through the side door of an explosion-proof housing. Formerly, the screw was in the hard-to-reach rear of the mount.

Graphical Method for Predicting Steady-State Temperature

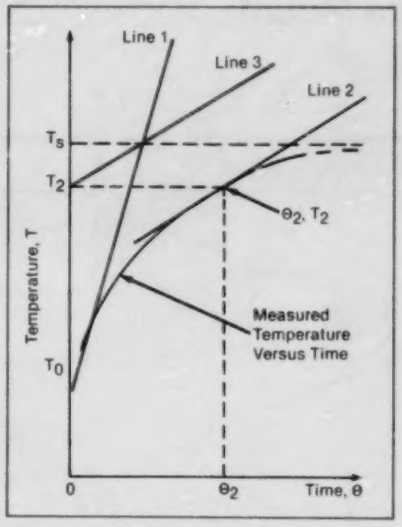
The temperature that a heated or cooled passive system will reach is predicted from temperature-versus-time curves.

Lyndon B. Johnson Space Center, Houston, Texas

A simple graphical construction method, originally developed for Space Shuttle applications, predicts the equilibrium temperature of a system that is being heated or cooled. The method assumes that the temperature relaxes exponentially toward an equilibrium value. The results can be obtained in minutes without a computer or complex calculations.

A plot of the early temperature-versus-time history of the system must first be determined by measurement for a given set of constant thermal conditions. From this plot, the ultimate steady-state temperature that the system will attain can be constructed. The construction method for a system being heated is as follows:

- A tangent is drawn to the temperature-versus-time curve at the point at which heating or cooling starts (line 1 in the figure).
- A second tangent is drawn to the curve at any point θ_2, T_2 (line 2 in the figure). Line 2 must have a slope different from that of line 1.
- Line 3 is drawn parallel to line 2 through temperature T_2 on the vertical axis. The temperature T_s at the intersection of lines 1 and 2 is the steady-state temperature.



The Intersection of Two Lines in a graphical construction gives the asymptotic temperature of a system. Developed for analyzing thermal anomalies during flights of the Space Shuttle, the graphical method is also applicable to everyday heating and cooling problems.

The procedure for a system being cooled is identical except that the slopes are negative.

The time θ_s for the system to progress through 99 percent of the temperature difference between the initial and steady-state values is computed from the equation

$$\theta_s = [(T_s - T_0)/(\text{slope of line 1})] \times \ln(100)$$

where T_0 is the temperature of the system at time zero. The 99-percent point is used as a convenient approximation, since theoretically it would take an infinitely long time to reach the final temperature.

The method is applicable to a variety of problems. Examples include the temperatures of buildings, powerplant or refinery components, or chemical reactors; voltages on charging or discharging capacitors; and concentrations of reactants in some chemical processes.

This work was done by Robert L. Case, Jr., of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 36 on the TSP Request Card.*
MSC-20835

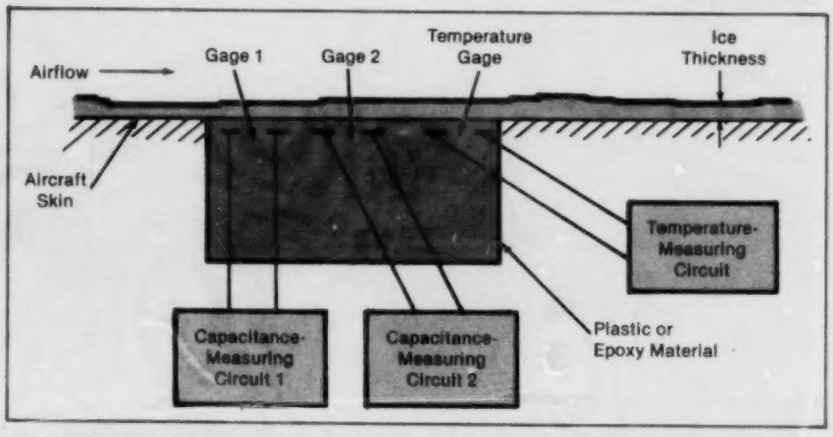
Ice Detector for Aircraft

The thickness of ice on aircraft is measured by a flush-mounted sensor.

Langley Research Center, Hampton, Virginia

A new three-gage device detects and measures the thickness of ice accumulation on the outside of aircraft. This information is required to determine whether efforts to remove the ice, such as heating or a change in flight speed or elevation, should be initiated.

The detector consists of the following: (a) a flush-mounted sensor with three separate components as shown in the figure; (b) a temperature-measuring circuit, the configuration of which is based on the type of sensor used (e.g., resistance film, thermocouple, integrated-circuit temperature sensor); (c) two capacitance-measuring circuits; and (d) a logic circuit that uses the outputs of the other three circuits to determine the presence of ice



The **Capacitance Gages** sense water or ice and measure the thickness. The temperature gage helps to distinguish between water and ice.

and its thickness.

Most solid insulating materials such as plastic or epoxy have dielectric constants of 3 to 5. Pure water and ice have dielectric constants near 80. If two conductors are embedded near the surface of such an insulator and a layer of pure water covers the surface, the capacitance between the two conductors is strongly influenced by the proximity of the high dielectric constant of water or ice.

Gage 1, with small conductors and a small gap, gives a large change in signal for a very small water thickness, with only slight differences for pure or conductive water. This gage detects water and ice. The temperature gage senses whether the skin is above or below freezing, thus differentiating between water and ice. The output signal for gage 2, which has a larger gap than gage 1, varies slowly with thickness and is nearly linear up to a fairly large thickness. Thus, gage 2 measures the thickness of the ice.

The logic circuit uses the temperature circuit to differentiate between water and ice. A comparator for capacitance-measuring circuit 1 detects whether any significant amounts of water or ice are present. The output of capacitance-measuring circuit 2 yields a certain level. Thus, this combination of circuits of the flush-mounted sensor allows the detection of water or ice and the measurement of the ice thickness on the outside of the aircraft skin.

This work was done by Leonard M. Weinstein of **Langley Research Center.** *No further documentation available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 21]. Refer to LAR-13403.

High-Performance Heat Pipe With Screen Mesh

Liquid is distributed more evenly in the evaporator section.

Lyndon B. Johnson Space Center, Houston, Texas

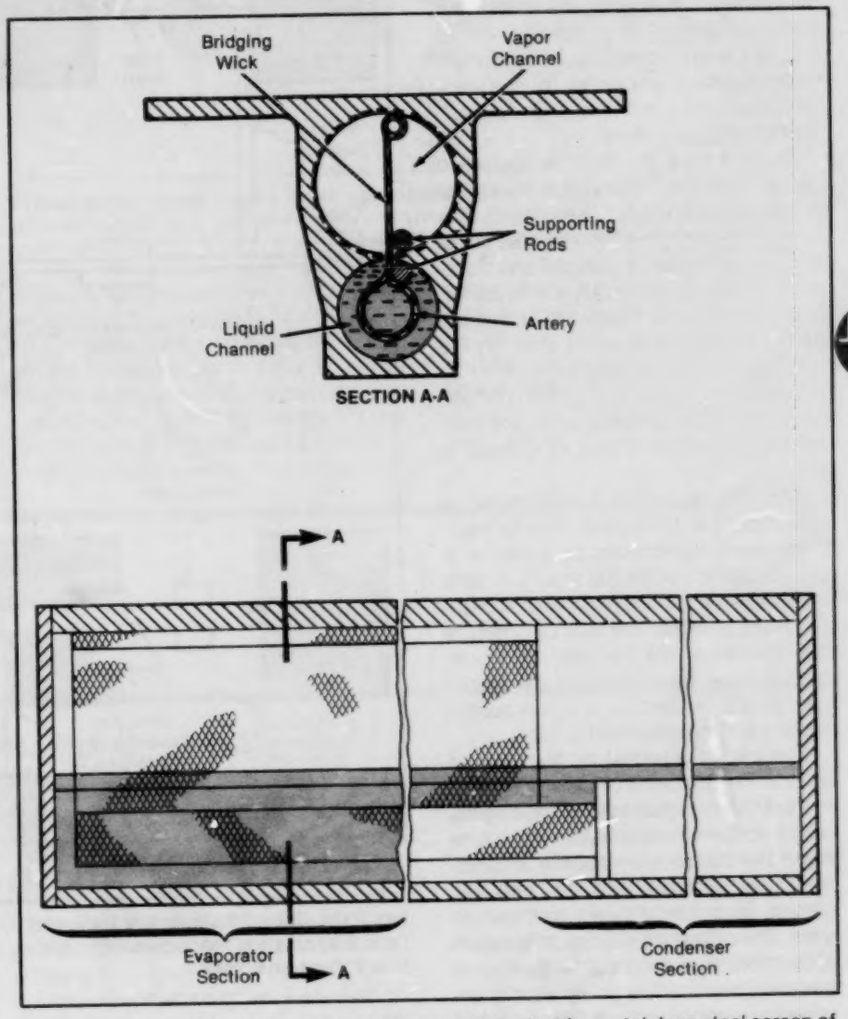
A rolled-screen insert increases the capacity of the heat pipe described in "High-Performance Heat Pipe" (MSC-20136), page 70, *NASA Tech Briefs*, Vol. 9, No. 2, (Summer 1985). The insert reduces the incidence of dryout at hotspots or during intervals of general thermal overload.

The insert is an artery and bridging wick formed from stainless-steel screen (see figure). The artery is centered in the liquid channel of the heat pipe but separated from the liquid-channel wall to reduce heat transfer from the wall into the artery. The bridging wick passes through the capillary channel between the liquid and vapor channels and makes contact with the wall of the vapor channel on the far side.

When the local or temporary heat transfer to the evaporator is high enough to boil all or part of the liquid away from the evaporator walls, the artery still contains liquid. The vapor in the annular-cross-sectional space between the liquid channel and the artery acts as a partial thermal insulator, thereby protecting the liquid in the artery from immediate boiling. The artery thus continues to distribute liquid to the parts of the evaporator that are not overheated, and the evaporator is protected against dryout and the consequent loss of heat-transfer capacity.

The bridging wick provides an auxiliary path for liquid to flow from the artery to the capillary slot and to the capillary grooves in the wall of the vapor channel. By feeding the liquid directly to the primary heat-input zone opposite the capillary channel, it helps to spread the liquid evenly onto the walls of the vapor channel, thereby further reducing the tendency toward dryout.

A porous plug made of four layers of the screen material allows liquid to pass but



The Improved Heat Pipe contains an artery and wick rolled from stainless-steel screen of 180 mesh (openings about 80 μm). The screen material helps to prevent dryout in the evaporator section by conducting liquid through hotspots and to the vapor-channel wall.

keeps the vapor that originated at hotspots from forcing liquid out of the condenser section of the liquid channel. The plug also helps to suppress flow instabilities arising from fluctuations of the vapor pressure.

This work was done by Joseph P. Alaric, Richard F. Brown, and Robert Kosson of Grumman Aerospace Corp. for **Johnson Space Center.** *For further information, Circle 32 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 21]. Refer to MSC-20497.

Measuring Gearbox Torque Loss

Accuracy is increased by measuring small torque differences directly.

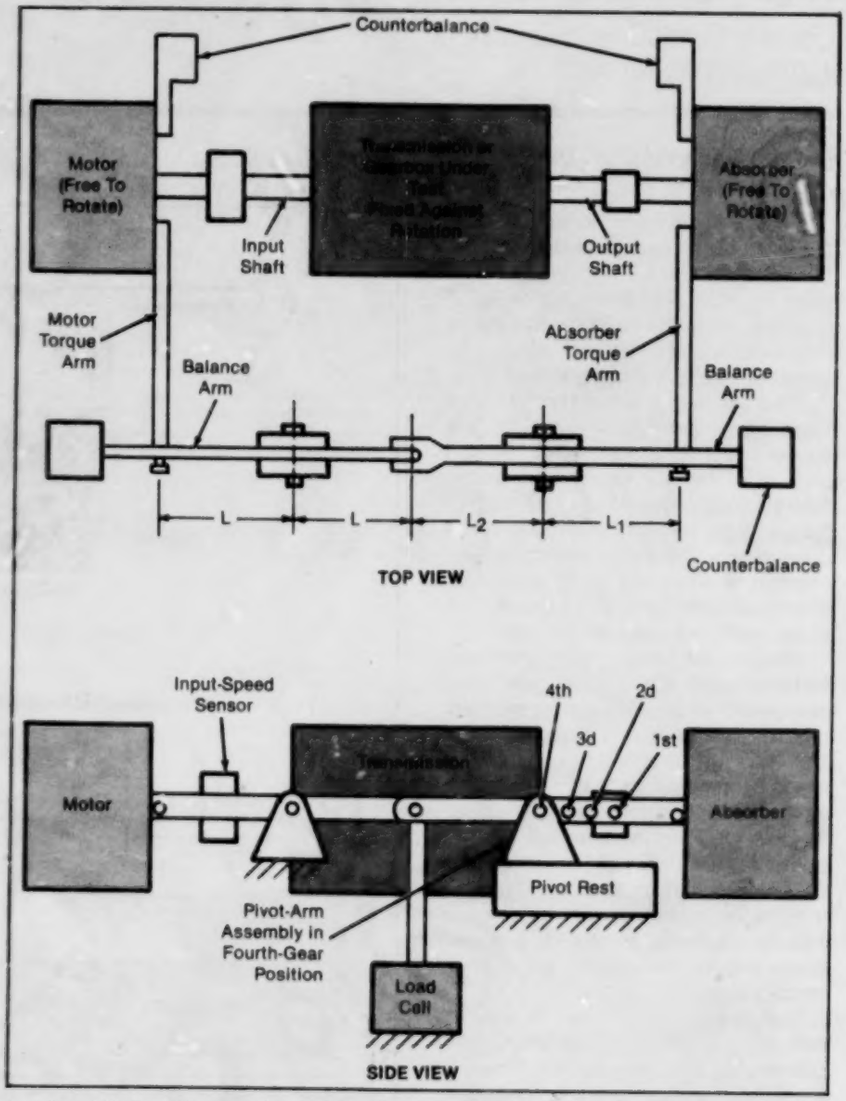
NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed apparatus would measure the portion of the input torque lost to friction in an automotive transmission or other gearbox. The apparatus, which would measure the difference between the input and gear-ratio-compensated output torques, would be more sensitive than previous measuring systems. Previously, the relatively large input and output torques were measured separately, mathematically corrected for the gear ratio, and subtracted — a procedure susceptible to large errors.

The motor and the absorber are free to rotate, while the transmission under test is fixed against rotation (see figure). The torque exerted by the motor on the transmission input shaft is reacted and transmitted by the motor torque arm to the left balance arm. Similarly, the torque exerted by the transmission output shaft on the absorber is reacted and transmitted by the absorber torque arm to the right balance arm. Both balance arms are connected to each other at a joint linked to load cell.

The left balance arm is constrained by a fixed pivot at its midpoint. The right balance arm is constrained by a pivot at a point selected so that the lever-arm ratio compensates for the torque multiplication in the gearbox: The ratio L_1/L_2 equals the inverse of the theoretical torque-multiplication (gear) ratio. In the fourth-gear position shown, $L_1 = L_2$ because in fourth gear, the gear ratio is 1 to 1.

The forces delivered by the balance arms to the load cell are thus proportional to the input and gear-ratio-compensated output torques, respectively. But since these two forces are opposite in direction, they subtract, and the load cell senses only the difference between them. The difference is a direct indication of the portion of the input torque lost in the transmission. The power loss is obtained by multiplying the input-torque loss by the input angular shaft speed.



Input and Output Torques Are Balanced by a mechanical linkage in this transmission-testing apparatus. The force applied to the load cell is proportional to the frictional torque loss in the transmission.

This work was done by Louis F. Schmidt of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 90 on the TSP Request Card.*

NPO-15794

Measuring Heat-Exchanger Water Leakage

Water-leakage rate can be measured directly.

Lyndon B. Johnson Space Center, Houston, Texas

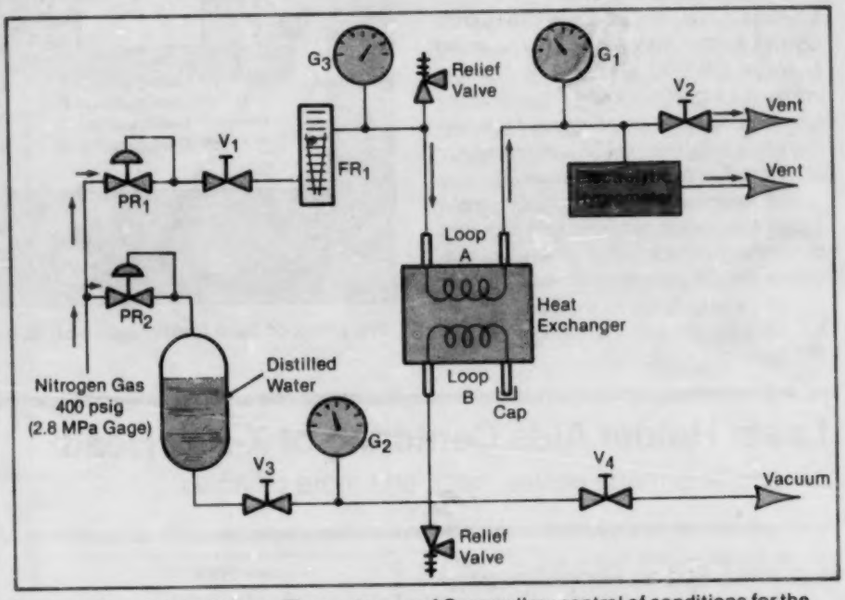
Water leakage in a heat exchanger is measured directly with the help of an electrolytic hygrometer. The new measurement method determines water concentrations of up to 2,000 parts per million with an accuracy of ± 5 percent.

Up to now, leakage has usually been measured by pressurizing the exchanger with gaseous helium and determining the helium leakage rate with a mass spectrometer. Converting the helium leakage to an equivalent water leakage is subject to considerable inaccuracy, however.

In the new technique, a flow of nitrogen gas is set up in one loop of the heat exchanger (see figure). The other loop is filled with water under pressure. The water concentration produced by leakage of the water into the nitrogen flow is measured by the hygrometer.

With pressure regulator PR_1, the flow of nitrogen in loop A of the exchanger is set at 20 standard ft^3/h (0.57 standard m^3/h), as indicated by flowmeter FR_1. With valve V_2, a back pressure of 10 to 15 psig (69 to 103 kPa gage) is established at gage G_1 in loop A. After the system stabilizes (in about 30 min), a reading of background water concentration is made with the hygrometer. This is the water vapor concentration that prevails without leakage.

Next, loop B is evacuated, filled with distilled water, and pressurized with nitrogen. Regulator PR_2 is adjusted so that the requisite pressure difference exists between the loops. The reading on gage G_2 will then be equal to the value on gage G_1 plus the pressure difference. After stabilization, the hygrometer is again read. Its indicated value less the background value represents the concentration caused by leakage. From this concentration, the known pressures, and the nitrogen flow rate, the leakage rate is then calculated in any convenient units such as cubic centimeters per hour.



Pressure Regulators, Valves, Flowmeters, and Gages allow control of conditions for the accurate measurement of water leakage in a heat exchanger. The concentration of water vapor created in loop A by leakage from loop B is measured and converted to a leakage rate.

This work was done by John Zampiceni of United Technologies Corp. for **Johnson Space Center.** *For further information, Circle 24 on the TSP Request Card.*
MSC-20811

Optimized Bolted Joint

Computer technique aids in joint optimization.

Langley Research Center, Hampton, Virginia

Load-sharing between fasteners in multirow bolted composite joints was computed by a nonlinear-analysis computer program. Input to the analysis was load-deflection data from 180 specimens tested as part of a program to develop the technology of structural joints for advanced transport aircraft.

The program predicted strengths of 20 large subcomponents representing strips from a wing-root chordwise splice. In most cases, the predictions were accurate to within a few percent of the test results. The highlight of the subcomponent testing was the consistent ability to predict gross section failure strains close to 0.005. This represents a considerable improvement over state-of-the-art values of 0.003 to 0.004.

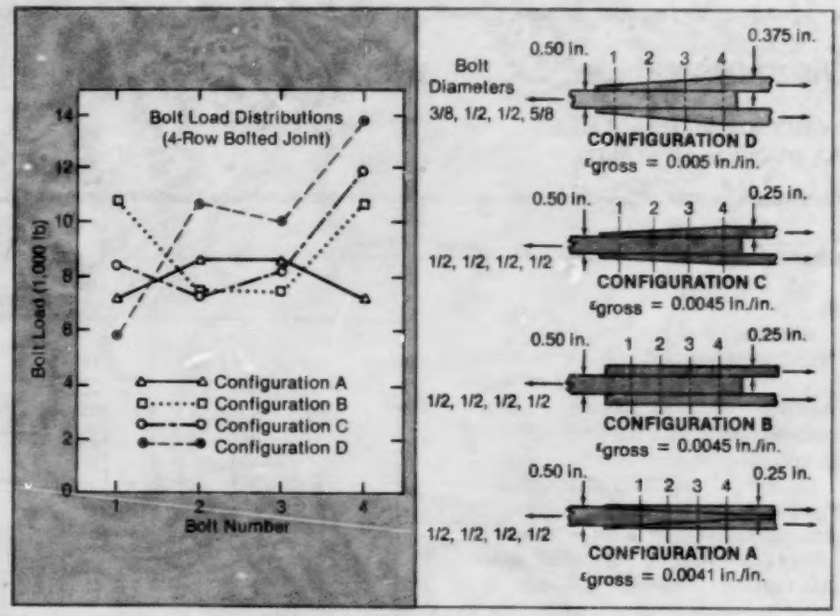
The computer program was used to analyze and compare multirow joints of different concepts, as shown in the figure. The configuration consisting of tapered splice plates in combination with a uniform skin thickness (configuration D) was predicted to be the most efficient joint design. The design was optimized by a sequence of iterations that minimized the bearing load and maximized the bypass load at the first row of fasteners while maximizing the load at the last (innermost) row of fasteners. The other configurations shown, which were less efficient, did not exhibit the progressive distribution of load in succeeding bolt

rows.

The bolt design optimization technique is applicable to major joints in composite materials for primary and secondary structures and should be generally applicable for metal joints as well. The technique allows optimizing manipulations of joint configuration in order to produce highest possible strain and load transfer for a given load situation.

This work was done by L. J. Hart-Smith, B. L. Bunin and D. J. Watts of McDonnell Douglas Corp. for **Langley Research Center.** *Further information may be found in NASA CR-3710 [83X-10287], "Critical Joints in Large Composite Aircraft Structure." A copy may be purchased [prepayment required] from NASA's Industrial Applications Centers listed on page 21.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 21]. Refer to LAR-13250.



The **Effect of Joint Configuration on Bolt Load Distribution** is shown for four designs.

Laser Holder Aids Centering of X-Ray Head

Alinement is made easier, safer, and more reliable.

Marshall Space Flight Center, Alabama

A laser holder used when alining an X-ray head makes the procedure safer and more reliable. Previously, X-ray heads used to inspect production welds had been aimed with the help of lasers attached by hose clamps. However, the clamps often slipped and caused misalinement. The lasers also hindered the placement of the heads, and the laser power cords were cumbersome. The new holder grips the laser securely, maintains alinement, does not interfere with head placement, and requires only one 110-V power cord.

The holder includes an open, boxlike clamp in which the laser is mounted on a movable lower plate (see Figure 1). A stationary upper plate is attached by bolts to the aluminum X-ray tubehead. The plates and clamp are made of aluminum. The clamp walls are attached to the lower plate with fillet welds.

The upper and lower plates are hinged together at one edge (see Figure 2). Near the opposite edge is a small force-

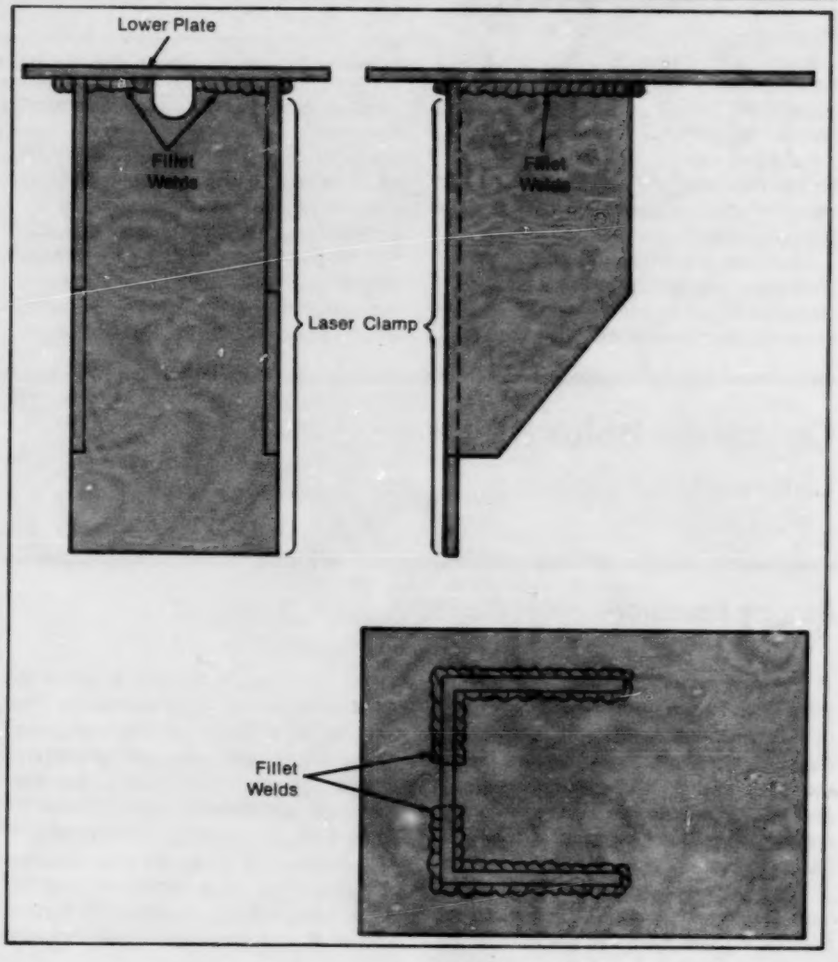
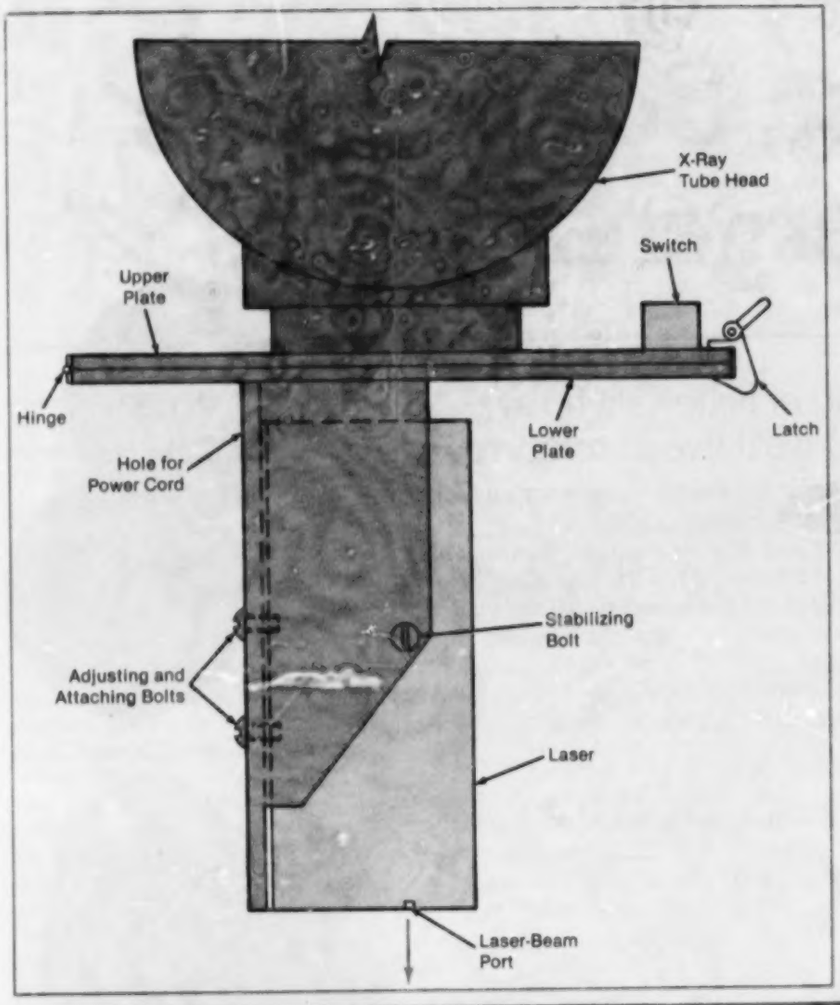


Figure 1. The **Lower Plate and Laser Clamp** are made of aluminum pieces welded together.



actuated power switch that closes when the plates swing together. A spring-loaded latch at the edge near the switch enables the two plates to be clamped together to secure the laser in the operating position.

When the laser is mounted on the bottom plate, it is alined with adjusting/attaching bolts so that the laser beam coincides with the X-ray beam axis. The laser is then immobilized relatively to the clamp by stabilizing bolts through the clamp walls.

To begin alinement of the X-ray head, the laser is swung into the operating position with the plates latched together. The laser beam is aimed at the designated spot on the part to be photographed by X-rays. The latch is then opened and the laser swung out of the way. The switch opens, turning the laser off. The laser is held out of the X-ray path while the part is exposed.

This work was done by D. V. Bulthuis and D. D. Kettering of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29067

Figure 2. The **Laser Holder Assembly** is attached to an X-ray head to enable the head to be alined optically before X-ray exposure. When the laser is in the operating position as shown here, the laser beam shines on the spot that will later be illuminated with X-rays.

Higher Sensitivity in X-Ray Photography

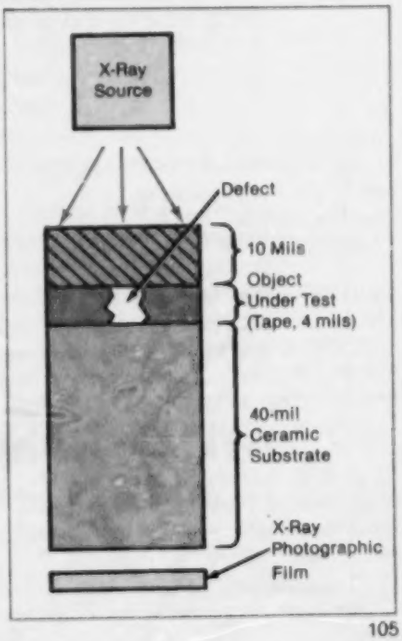
Hidden defects are revealed if the X-ray energy is decreased as the exposure progresses.

Marshall Space Flight Center, Alabama

Declining-potential X-ray photography has been used to detect fractures in a thin metal sheet covered by an unbroken sheet of twice the thickness. Originally developed to check solder connections on multilayer circuit boards, the technique has potential for other nondestructive testing.

A typical test setup is shown in the figure. As the film is exposed, the voltage applied to the X-ray tube is decreased. The declining potential results in a corresponding decline in the maximum X-ray energy and a corresponding decrease in the penetrating power of the X-rays.

At some point during the exposure, the penetrating power reaches a threshold below which the radiation passing through the total material thickness is insufficient to appreciably affect the film. However, since



The **Setup for Declining-Potential X-ray Photography** is shown above. The photograph below was taken using ASA 400 film with exposures of 10 s at 60 kV followed by 5 s at 30 kV. It reveals a hidden fracture in an aluminum sheet only 19 mils (0.48 mm) thick, covered by an unfractured sheet 38 mils (0.97 mm) thick.

the defect region is thinner than the rest of the material, it has a lower penetration threshold, and enough radiation passes

Amer, Bozich, Hess, Juergens & Ross

These are the kind of Fellows who are making the world we'll live in tomorrow.

These are five top achievers in technology—newly named McDonnell Douglas Engineering and Research Fellows.

Our company searches out and develops men and women who are creative leaders in their work. We surround them with challenges to be met. We provide them with the facilities to fulfill their potential and with opportunities for advancement in the fields in which they do their best work.

Amer, Bozich, Hess, Juergens and Ross bring progress and honor to our company. They represent in the world of technology what the Albin Polasek sculpture shown here represents in art: Mankind carving its own destiny.

Kenneth B. Amer has gained industry-wide recognition for his substantial contributions to rotary-wing aeronautics. With his remarkable grasp of all technical aspects of helicopter design and testing, he was a key team member in the development of the OH-6A and AH-64 helicopters.

Dr. William F. Bozich has applied his expertise to the investigation of laser vulnerability, lethality, and hardening of missiles and aircraft to laser radiation. Two of his laser hardening design concepts are currently under development in SDI research programs.

John L. Hess is an aerodynamics engineer whose nearly 30 years' work with air flow and acoustics radiation problems has led to worldwide textbook standards for aircraft design. His test methods are used daily throughout industry and have influenced the design of all of our own commercial jet transports.

Raymond J. Juergens has brought exceptional talent and ingenuity to the advancement of composite materials technology. His knowledge and experience in non-metallics has been a significant factor in the success of our company's F-15, F/A-18, and AV-8B aircraft.

Monte Ross has pioneered in the development of space laser communications. Research and development launched under his leadership led to the first lasercom equipment to be space qualified, and has brought important advances in laser communications to submarines.

"Man Carving Out His Destiny"

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Circle Reader Action No. 373

The Roster of Fellows

Arner, Bozich, Hess, Juergens and Ross join these previously named top achievers in technology, listed here with their special areas of expertise:

Eugene C. Adam. Aircraft crew station design and information display.

Dr. Norman R. Byrd. Materials science.

Dr. Tuncer Cebeci. Computational fluid mechanics and theoretical aeronautics.

Paul H. Denke. Finite-element structural analysis.

Dr. William K. Douglas. Space flight medicine and acceleration physiology.

Saul Fast. Avionics, communications and solid state electronic warfare.

Dr. James I. Gimlett. Optical and electro-optical system technology.

Dr. Virgil V. Griffith. Digital electronic system architecture.

Frank Laacke. Fighter aircraft design.

James G. Laird. Radar design and analysis.

Francis D. McVey. Computer-aided engineering for aerospace system development.

John Mackey. Human interactions with technology.

Lawrence D. Perlmutter. Navigation, guidance, control, and orbital flight mechanics.

Richard A. Rawe. Fracture mechanics.

Dr. Daniel L. Rosamond. Orbital mechanics applied to spacecraft and missile guidance.

Dr. Miklos Sajben. Flow fields in inlets and ducts.

Dr. Robert J. Sunderland. Adhesive bonding, corrosion and erosion resistance.

John C. Weitekamp. Fighter aircraft, missile and spacecraft design.

Dr. Clarence J. Wolf. Environmentally induced degradation of electrical insulation.

Dr. Rainer Zuleeg. Gallium arsenide microcircuitry.

through this region to affect the film.

Thus, it is possible to obtain contrast between the defective and "good" regions even without knowing the exact threshold voltage or the exact nature of the defect. Of course, a knowledge of the properties of the object under test and the exposure parameters of previous successful X-ray photographs aids in selecting the declining-potential waveform, the film, and the other test conditions.

The technique is able to reveal a thin layer of transparent plastic tape beneath a large-scale integrated circuit with a 10-mil (0.25-mm) metal lid and a 40-mil (1-mm) ceramic substrate. Its ability to reveal hidden fractures in metal sheet is indicated by the accompanying photograph. The technique may also have medical uses in the detection of bone fractures.

This work was done by Richard N. Buggle of Honeywell, Inc., for **Marshall Space Flight Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 21]. Refer to MFS-28026.

Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to make raw programs available to the public. For information on program price, size, and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

Simplified Ride-Comfort Program

Vibration and noise contributions to discomfort are quantified.

RIDEQUL estimates passenger ride comfort within air- and surface-transportation systems. It provides engineers with a reliable method of objectively predicting and evaluating vehicle ride quality. RIDEQUL transforms individual elements of the noise and vibration characteristics of a vehicle into subjective units and combines these units to produce a single discomfort index. This index can be used to estimate the total ride quality within a vehicle and to make comparative ride-comfort assessments between vehicles. RIDEQUL permits the routine processing and conversion of physical ride-environment data into discomfort estimates that relate directly to passenger acceptance of the environment.

RIDEQUL reflects human frequency sensitivity to vibration by applying frequency-weighting factors to each axis of vibration, thus eliminating the need to make judgments of spectral characteristics. The weightings used in RIDEQUL were obtained from subjective comfort ratings of more than 3,000 persons exposed to controlled environments in a passenger ride-quality simulator. RIDEQUL also incorporates the effects of interior noise levels within six octave bands. A-weighted sound levels are used. An optional ride-duration correction can also be included in the analysis to account for passenger adaptation to vibration on trips of less than 2 hours.

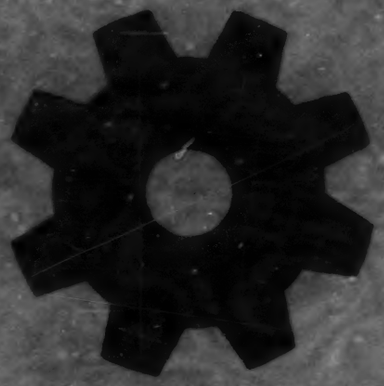
RIDEQUL accepts vibration input for each of five axes (vertical, lateral, longitudinal, pitch, and roll). Vertical, lateral, and roll axes can be specified as having sinusoidal vibration, and any axis can have a random vibration. If random vibration is to be the basis, TIFT-formatted data of the power spectral density of the vibration over time must be entered. RIDEQUL computes the discomfort due to vibration in each axis and then sums the axial components of vibration according to specific combined-axis algorithms. This total vibration discomfort is then corrected for the trip duration if desired.

Noise-discomfort contributions are calculated for each of the six octave bands and are then combined. The corrected vibration result is added to the total noise contribution to produce a final, overall, estimated discomfort index. In addition to the overall index, the engineer can also identify the subjective discomfort values due to individual elements of the vibration and noise.

This program is written in FORTRAN 77 for interactive or batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 70K (octal) of 60-bit words. This program was developed in 1984.

This program was written by Jack D. Leatherwood of **Langley Research Center** *and Linda M. Barker of System Development Corp. For further information, Circle 73 on the TSP Request Card.*
LAR-13289

Machinery



Hardware, Techniques, and Processes

108 Transfer Mechanisms for Heavy Loads
109 Multileg Heat-Pipe Evaporator
110 Manual "Guillotine" Wirecutter
110 Manifold Coal-Slurry Transport System
111 Heat Pipe Proceeds and Reheats Dehumidified Air
113 Jig for Removing Rivets
114 Detection of Machining Chips by Pressure Reversal
114 Digital Controller for a Remote Manipulator
115 Portable Hydraulic Powerpack
116 Oscillation Damper With Two Spring Rates
116 Dual-Flow-Rate Valve
117 Rotary Joints With Electrical Connections
118 Emergency Brake for Tracked Vehicles
119 "Curtainless" Window
120 Secure Disposal Container for Classified Papers
120 Rotating Drive for Electrical-Arc Machining
121 Variable-Displacement Hydraulic Drive Unit

Books and Reports

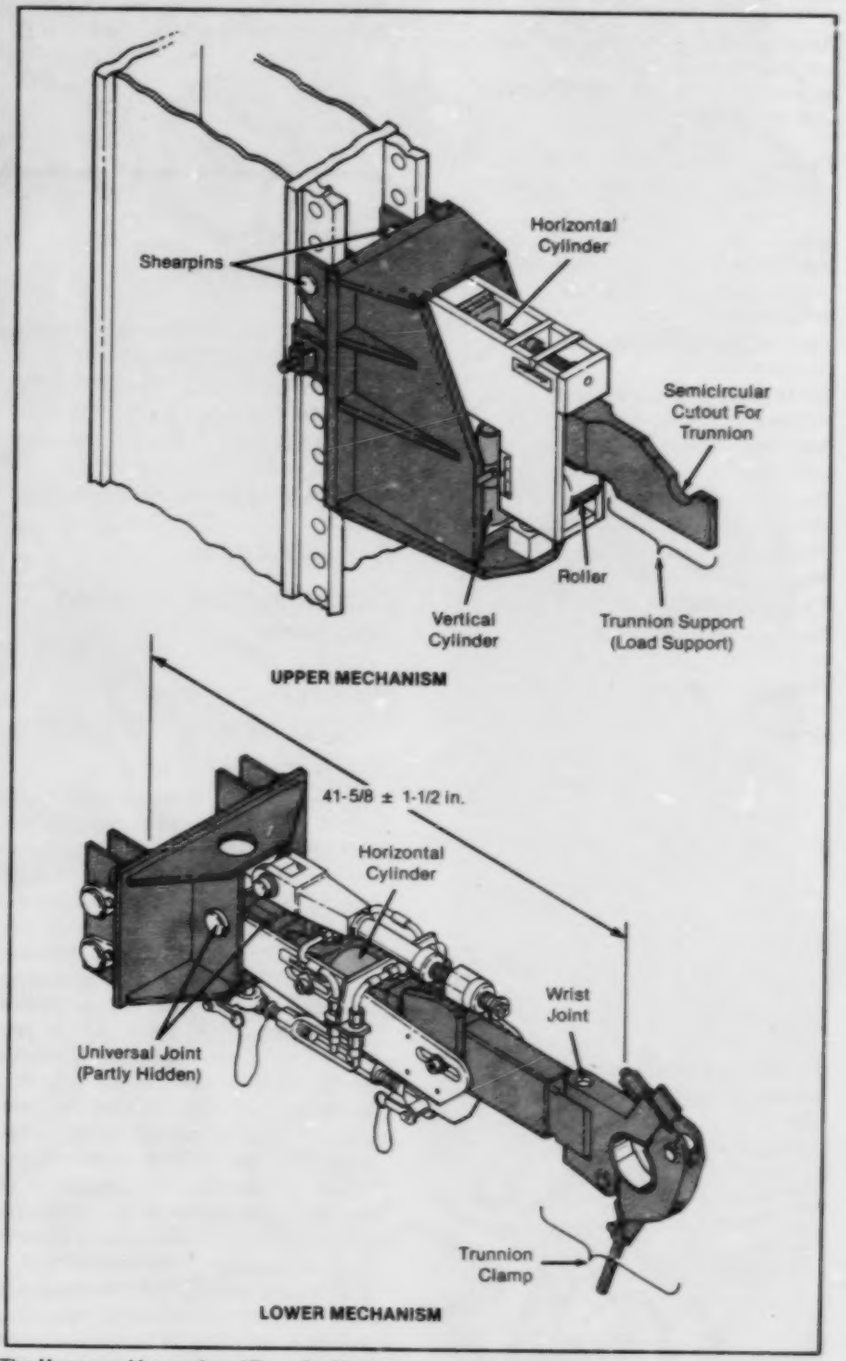
121 Survey of Hand Controllers for Teleoperation

Transfer Mechanisms for Heavy Loads

A soft hydraulic system gently maneuvers loads.

John F. Kennedy Space Center, Kennedy Space Center, Florida

New load-bearing mechanisms produce small motions to transport heavy loads. In the present design, they grasp trunnions on Space Shuttle payload modules. With modifications, they may be useful in transferring large loads in rail-



The **Upper and Lower Load-Transfer Mechanisms** attach through mounting holes in a vertical beam which is adjustable for gross positioning. The fine positioning of the load is accomplished by hydraulic cylinders that move the trunnion support and trunnion clamp through short distances.

roads, agriculture, shipping, manufacturing, and even precision assembly of large items.

There are two mechanisms in a set (see figure): An upper one that lifts the load and moves it horizontally and a lower one that pushes or pulls horizontally but allows free vertical motion over a limited range. Both mechanisms are held by shearpins on a vertical beam. To provide a range of vertical positions for different loads, the holes are located along the beam at 10-cm intervals.

The upper mechanism supports loads up to 39 klb (173 kN) and exerts a horizontal force of as much as 16 klb (71 kN) toward or away from the beam. The load is lifted by a single-acting hydraulic cylinder, while the horizontal force is exerted by a double-acting hydraulic cylinder.

The range of vertical motion is +1, −2 in. (+2.5, −5.1 cm), while the horizontal range is ±1.5 in. (±3.8 cm). In addition, coarse-thread screws enable lateral adjustments of ±0.5 in. (±1.3 cm) across the beam. While small, these ranges are just sufficient to enable the trunnion supports to move out from under the trunnions.

The lower mechanism also includes a double-acting, 16-klb (71-kN) horizontal cylinder. It contains no vertical cylinder, however: Instead, universal and wrist joints allow the load to move freely in the vertical and lateral directions.

The hydraulic system includes a gas accumulator that acts as a load-relief spring. This is necessary to cushion the load and its receptacles against impacts and distorting forces due to misalinement and vibration. The gas space in the accumulator is filled with nitrogen to a pressure that gives the desired spring stiffness. The damper-needle setting determines the dynamic response of the system by controlling the rate of flow of hydraulic fluid between the accumulator and the cylinder.

The hydraulic fuild is water with 5 percent lubricant. (Water was chosen because, in the Space Shuttle, it is unlikely to cause damage if spilled.) The hydraulic system is repeated for each direction of each cylinder, so that independent horizontal and vertical displacements and individually adjustable spring and damping rates are available at each trunnion support for precise, gentle positioning of the load.

This work was done by Vincent Cassisi of **Kennedy Space Center.** *For further information, Circle 48 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 21]. Refer to KSC-11292.

Multileg Heat-Pipe Evaporator

Parallel pipes provide high heat flow from a small heat exchanger.

Lyndon B. Johnson Space Center, Houston, Texas

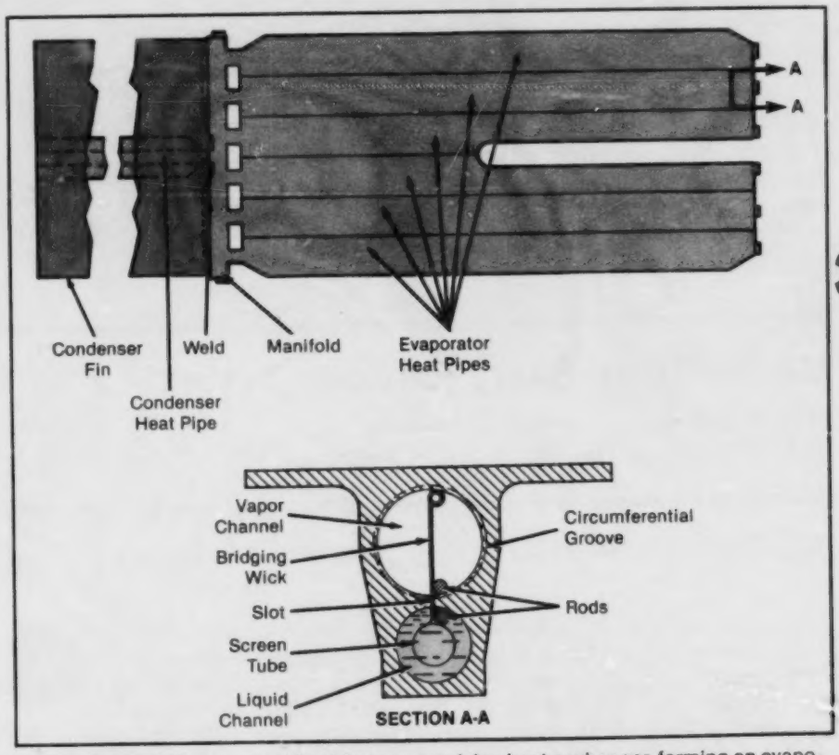
Multiple, parallel, short heat pipes instead of a single, long heat pipe are used on the evaporator of a heat-transport system. As a result, the evaporator is compact rather than extended and is more compatible with existing heat-exchanger geometries. A prototype six-pipe evaporator is only 0.3 m wide and 0.71 m long. With ammonia as the working fluid, it transports heat to a finned condenser at a rate of 1,200 W.

To ensure high heat-transport capacity, each extruded aluminum pipe contains two channels — one for vapor and one for liquid (see figure). Liquid from the condenser flows through the liquid channel and via a bridging wick into circumferential evaporator grooves in the vapor channel. The operation of the heat pipe is explained in more detail in the preceding article.

At the condenser end, the heat pipes are welded to a manifold. In turn, the manifold is welded to a single condenser pipe, which is a two-channel extruded tube like the evaporator pipes. A fin on the condenser pipe radiates heat into the surrounding space so that the vapor in the pipe condenses into a liquid and returns to the evaporator.

This work was done by Joseph P. Alario and Robert A. Haslett of Grumman Aerospace Corp. for **Johnson Space Center.** *For further information, Circle 34 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center, [see page 21]. Refer to MSC-20812.



Six Parallel Heat Pipes extract heat from an overlying heat exchanger, forming an evaporator. The vapor channel in a pipe contains a wick that extends into a screen tube in the liquid channel. Rods in each channel hold the wick and screen tube in place.

Manual "Guillotine" Wirecutter

Many wires are cut in one operation.

Lyndon B. Johnson Space Center, Houston, Texas

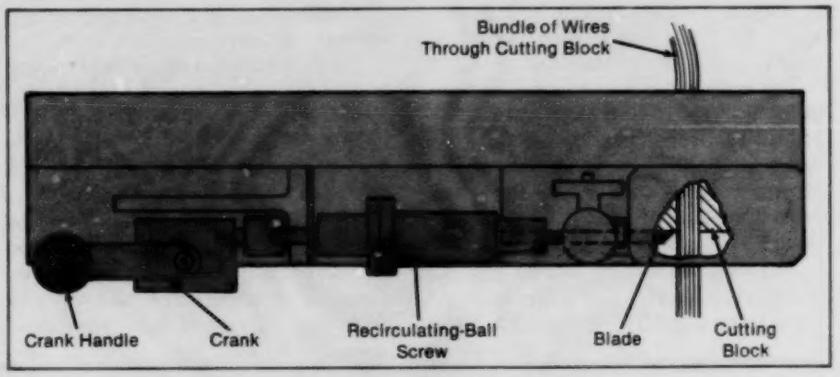
A "guillotine" wirecutter saves operator time and energy when severing a bundle of wires. The cutter was designed to help astronauts break through spacecraft payload cables while working outside the spacecraft. It could be used on Earth for emergency cable separation or cable trimming in production.

The conventional technique for cutting bundles of wires is to cut the wires individually or in small groups with diagonal cutting pliers. To speed the process, guillotine-style cutters have been produced, but they require hydraulic or compressed-air power sources.

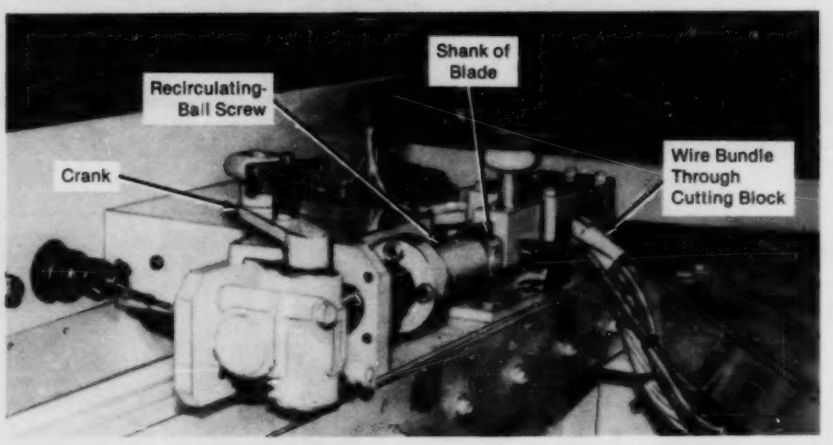
In the manual guillotine cutter (see figure), the wires are prestrung through the cutting block. In the case of a vehicle or structure with installed wires, the wires remain in the block during normal operation, ready to be cut at a moment's notice.

To cut the wires, the operator turns a crank, which drives a recirculating-ball screw. The mechanical advantage of the screw enables it to develop enough force to push the blade through the bundle of wires. In the original spacecraft application, the time to cut all the wires was about a minute.

This work was done by Wayne J. Wedlake of McDonnell Douglas Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20926



The Guillotine Wirecutter is powered by a handcrank. The crank turns a recirculating-ball screw, which pushes the blade through the bundle of wires in the cutting block.



Manifold Coal-Slurry Transport System

Feeding several slurry pipes into a main pipeline reduces congestion in coal mines.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed system for pumping a coal slurry out of a mine can serve several continuous-mining machines simultaneously, yet allows individual excavators to be stopped without disrupting production from the other machines. The system is based on a manifold concept in which feeder pipelines from each working entry are joined to a main pipeline that carries the coal slurry out of the panel and onto the surface. The manifold concept makes coal-slurry haulage much simpler than it is with existing slurry systems. For example, in a room-and-pillar operation utilizing slurry haulage, it is necessary to run a separate pipeline out of the panel for each working excavator. This limits the number of entries that can be operated simultaneously due to the pipeline congestion. By manifolding the pipelines, one reduces the congestion substantially, allowing more working faces, thus higher production.

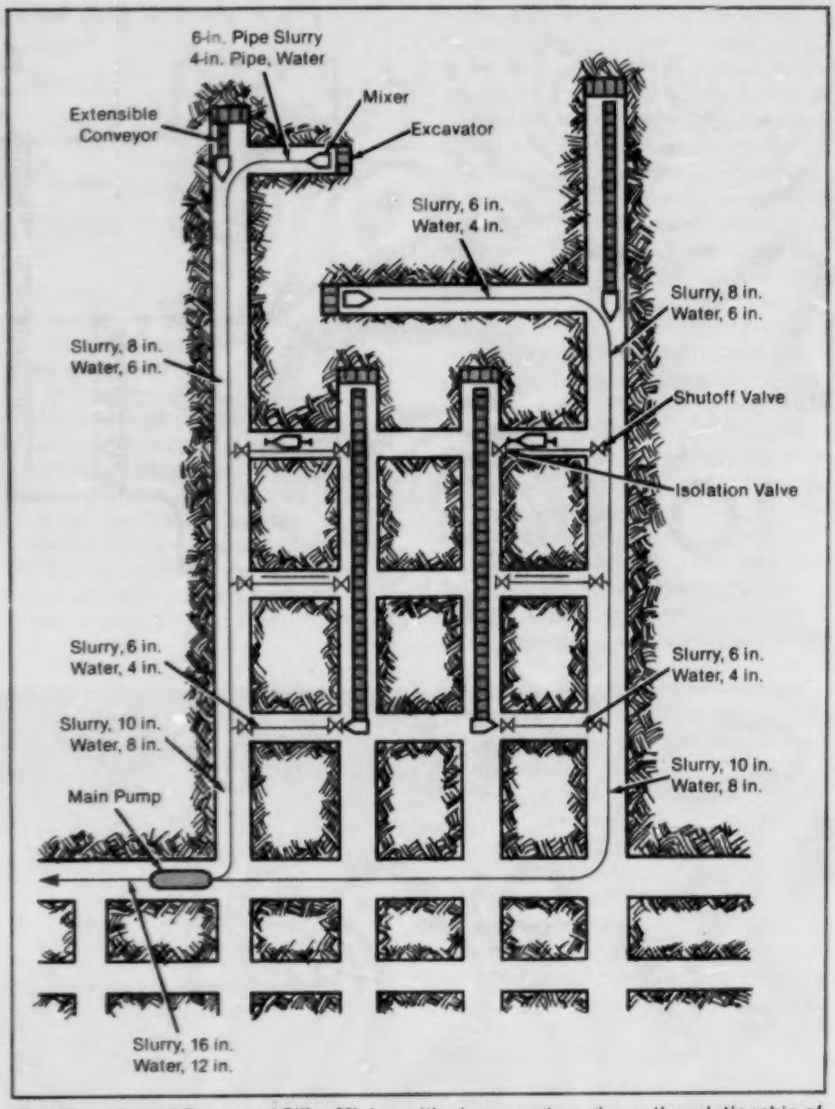
In the manifold system (shown in the figure), the excavators drag extensible conveyors, which transport the coal from the advancing excavator, to a portable stationary slurry mixer/injector located in an open crosscut. When a conveyor extends to its full length, the excavator is stopped, and the slurry injector is advanced. This brief shutdown is necessary about once a day. The injector is ad-

vanced when it is disconnected from the feeder pipelines in the crosscut, and then the conveyor is retracted, which pulls the injector up into the next crosscut where another preinstalled set of feeder pipelines is waiting. The pipe connections are made, and mining resumes. Meanwhile, the other excavators continue feeding coal to the main pipe without interruption. This is possible because of an isolation valve in the crosscut that bypasses water into the slurry pipeline when the injector shuts down, thus preventing backwash and maintaining constant flow in the pipeline.

An isolation valve consists of three valves operated in unison: a slurry valve, a water valve, and a bypass valve. Normally, the water valve and the slurry valve would be open so that water could enter the mixer and slurry could leave it. When the mixer is to be shut down, however, the slurry and water valves are closed, and the bypass valve is opened. The bypass valve diverts water from the mixer, sending the water from the supply pipe directly into the feeder pipe. This maintains an adequate waterflow in the main pipe so that the coal particles do not settle out of the slurry and clog the pipe.

Shutoff valves are provided at every point where a feeder pipe joins the main pipe. These valves cut off feeder lines for disassembly and advance into another open crosscut, allowing flow in the main pipe to continue. They also close off feeder sections in case of a leak or other emergency.

The flow velocity in the pipes is estimated to be about 10 ft/s (3 m/s), which is high enough to prevent sedimentation but not so high as to wear the pipes excessively. The crushed coal is mixed with 70 volume percent water, yielding a slurry about three times as viscous as water. This viscosity can be handled without excessive pumping power. The pipe diameters are at least three times greater than the largest-expected coal particle; therefore, there would be little chance of the pipes becoming plugged, provided that adequate flow is maintained.



This Plan View of Room-and-Pillar Mining with six excavators shows the relationship of excavators, extensible conveyors, mixers, slurry feeder pipes, and slurry main pipes. Diameters of pipes are indicated. The main pump lifts the slurry from the mine to the surface.

This work was done by Sidney G. Liddle, Jay M. Estus, and Milton L. Lavin of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 38 on the TSP Request Card.*
NPO-16471

Heat Pipe Precools and Reheats Dehumidified Air

Precooling and reheating by the heat pipe reduces the operating costs of air-conditioning.

John F. Kennedy Space Center, Florida

Heat-pipe technology is being brought to bear on the problem of conserving air-conditioning energy in a hot, humid environment. In an experimental installation in Florida, an air-to-air heat-pipe exchanger is being used to precool the returning warm air before it enters the cooling coil and to heat the chilled air before it enters the air-conditioned space (see figure). A large-scale heat-pipe system has also been simulated on a computer.

The conditioning of air for comfort in a hot, humid climate requires a substantial amount of energy to condense and remove the moisture. The conventional practice is to chill the air well below the comfortable temperature to reduce its relative humidity to the comfort level then

to reheat the air with an electric resistance heater, or with such other means as hot-water coils, steam coils, or waste heat from condenser, so that it is not excessively cold when it enters the room.

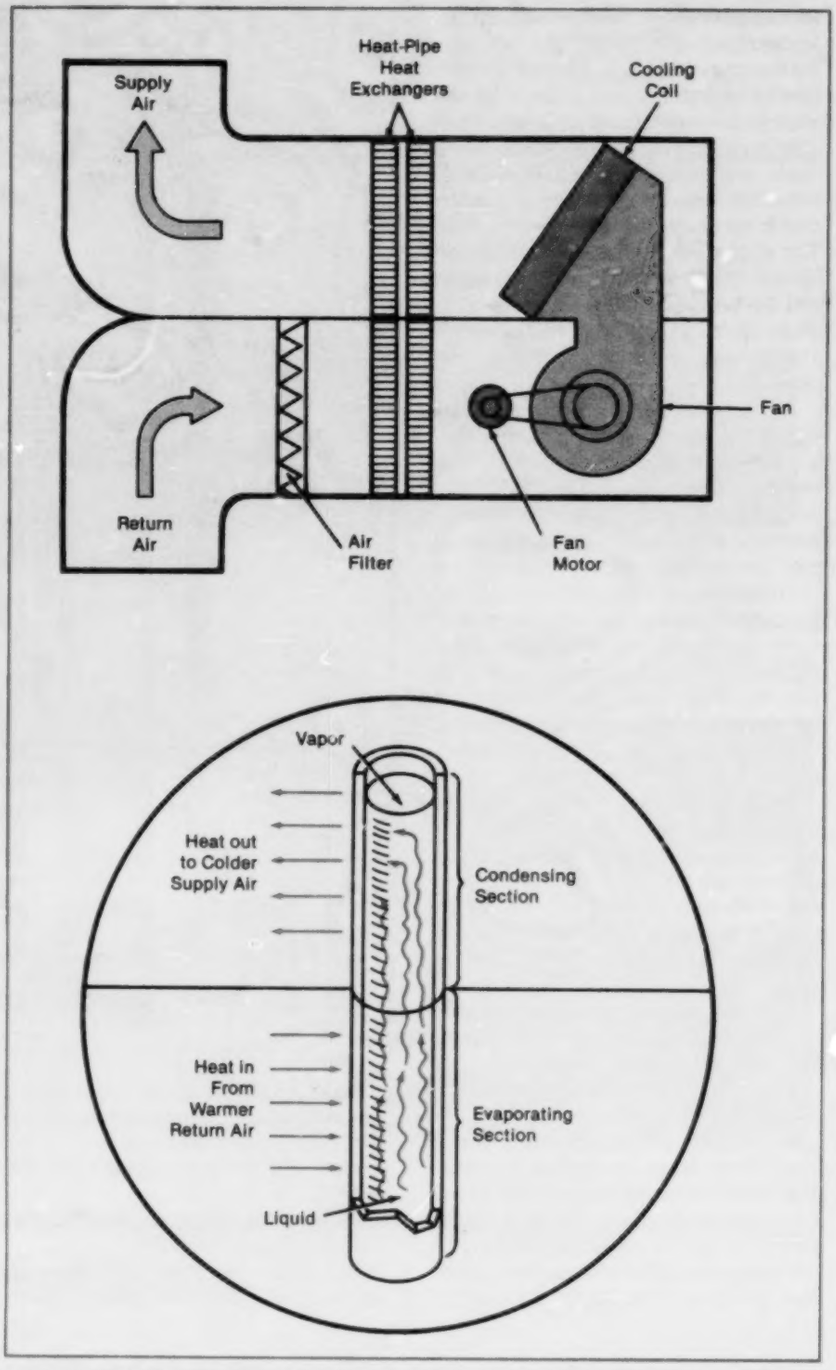
Reheating is obviously a wasteful process. Not only is energy added to the air to increase its temperature, but the same energy must be removed by the refrigeration machinery when the air is recirculated. In addition to energy costs, reheating increases the costs of equipment and maintenance.

In a system equipped with a heat-pipe heat exchanger, the evaporator section of the heat pipe is in the return-air duct. Liquid inside the evaporator absorbs heat from the warmer return air, evaporates, and passes to the condenser section as vapor. In the condenser, which is in the supply-air duct, the vapor condenses on the inner wall of the heat pipe, thereby transferring heat to the colder supply air. The newly condensed liquid is returned to the evaporator by gravity, capillary action, osmosis, or pumping.

The working fluid may be water or a commercial refrigerant. Wicks around the inner periphery of the heat pipe ensure that the liquid wets the surface for efficient heat transfer. The heat pipe functions well with a relatively small temperature difference between the evaporator and the condenser. Unlike heat pipes for space applications, the pipes for air-conditioning do not have to be particularly small in diameter or meet other stringent requirements. They are therefore fairly simple and inexpensive to manufacture.

A simple thermosiphon heat-pipe heat exchanger, developed and built by the Dinh Co., Alachua, Florida, is used in the Florida experiment. The heat exhanger is constructed from two refrigerant-condenser coils joined by copper tubing. The assembly is evacuated and filled with refrigerant R12 (dichlorodifluoromethane). It has performed well in the first phase of testing.

The presence of heat pipes in the ducts will obstruct the airflow appreciably, and fan power will have to be increased accordingly. However, the fact that the supply air need not be reheated more than compensates for the extra fan requirement. Any increase in the cost of equipment due to the installation of heat-pipe heat exchangers is expected to be recovered in energy savings during a service period of 2 years or less. In the case of new installations, the cost of the heat-pipe heat exchanger is usually compensated by the smaller size of the air-conditioning plant, which can now be sized to exclude the extra load of the reheating.



Warm Air Returned from an air-conditioned space and cooled air supplied to it are precooled and reheated, respectively, by each other through a heat pipe.

This work was done by Robert C. Koning, Wallace H. Boggs, and U. Reed Barnett of **Kennedy Space Center** *and Khanh Dinh of the Dinh Co. for Kennedy Space Center. For further information, Circle 65 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 21]. Refer to KSC-11311.

Jig for Removing Rivets

A drill-press jig is used to remove improperly installed rivets.

Lyndon B. Johnson Space Center, Houston, Texas

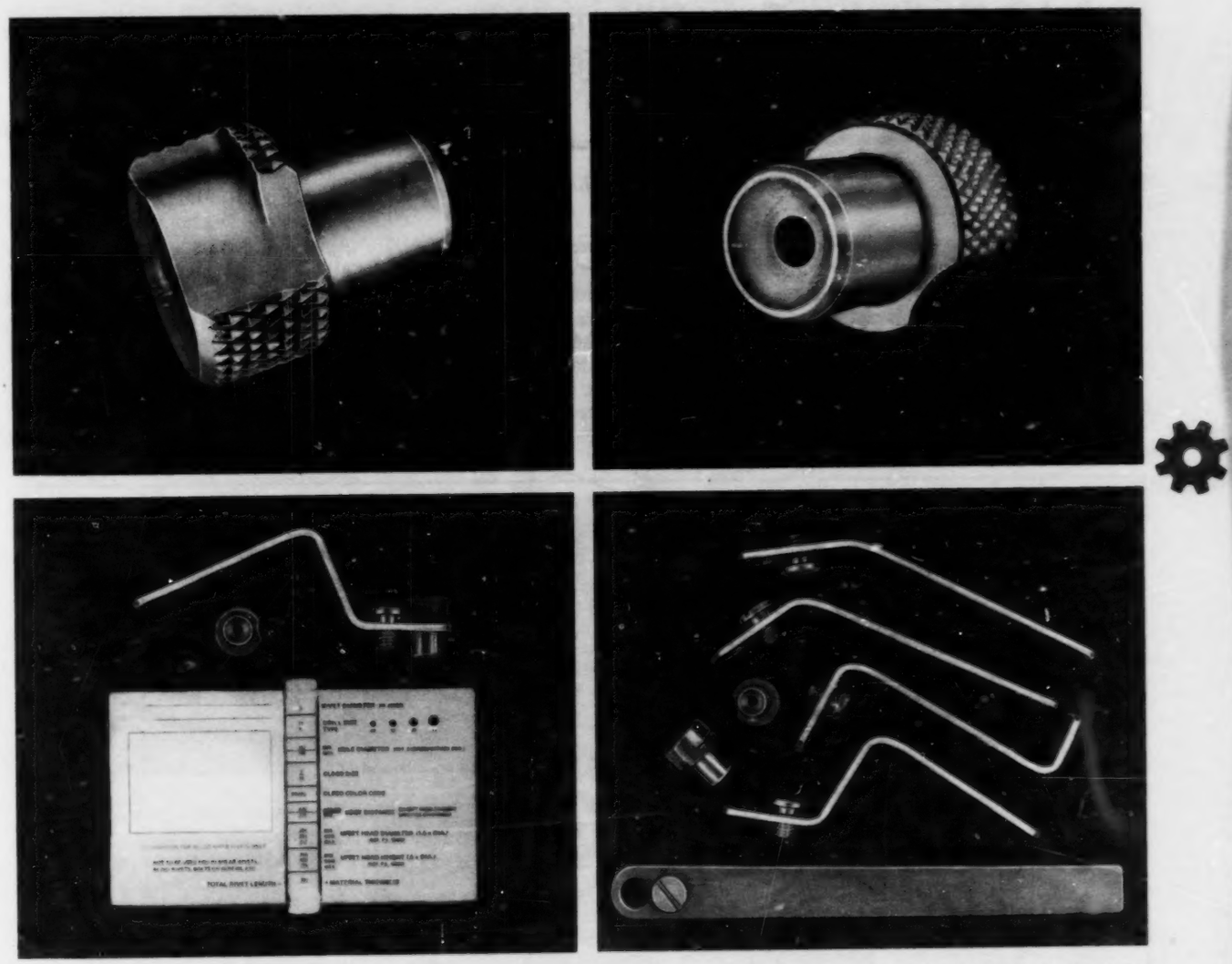
A drill-press jig makes it possible to drill accurately-centered, straight holes through rivets. The key component of the jig is a drill bushing with a spherical recess machined into the base. The contour of the recess matches the contour of the rivet head.

Rivets that have not been installed correctly are usually very difficult to remove and replace. The obvious method is to drill out the rivet along the axis and scrape away the rivet metal that remains after drilling. Without the jig, however, the drill bit tends to slip off the rivet head, damaging the surrounding material, or to wander, creating an oversized hole. Often, it seems preferable to scrap riveted parts rather than refasten them.

The modified bushing and the components of the jig are shown in the figure. The bushing is slipped into a hole in a handle, and the flat head of a screw on the handle mates with a notch machined into the bushing. The bushing is placed over the rivet, and the drill is inserted in the bushing. An operator holds the jig handle with one hand and controls the drill with the other hand. The handle and screw head thus hold the drill bit in place over the center of the rivet so that the rivet can be drilled out through its axis. With the rivet thus removed, the parts can be separated and refastened or reused elsewhere.

This work was done by Thomas P. Roebuck and Al E. Houser of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 21]. Refer to MSC-20757.



The **Contoured Bushing** (top) fits over the rivet head. The operator holds the bushing in place over the rivet with the handle (bottom left) while inserting the bit of the drill into the bushing bore. Standard bushings can be adapted to a variety of rivet sizes. Similarly, the handle length and offset angle can be adapted to the geometry of a particular removal situation (bottom right).

Detection of Machining Chips by Pressure Reversal

Inaccessible interior spaces are inspected acoustically.

Marshall Space Flight Center, Alabama

Loose machining chips or other particulate contaminants in certain machinery can be detected by the sound they produce when they are moved by a rapidly-reversed pressure differential. Currently used techniques for identifying loose contaminants, such as high-volume water flushes and borescope inspection of components, cannot reach all parts of turbopumps and other intricate assemblies.

In acoustic inspection, the inlet and outlet ports of a component are connected to pneumatic hoses of an apparatus that rapidly reverses the induced pressure differential. If there are loose particles inside this component, they will generate noise that is detected by a series of contact microphones attached to the component. The noise indicates the general location of the contaminants, and its characteristic may help in identifying the particles from their acoustic signatures.

This work was done by Lynn M. Wyett of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29076

Digital Controller for a Remote Manipulator

Sealed forces and displacements are fed back to the operator to facilitate control.

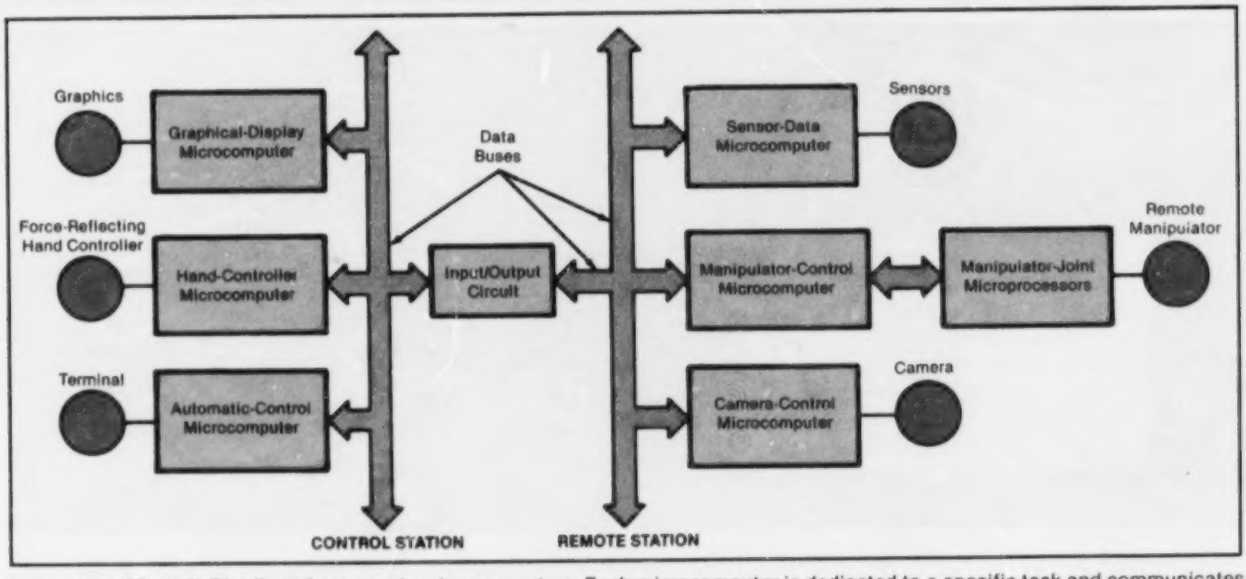
NASA's Jet Propulsion Laboratory, Pasadena, California

A controller for a remote manipulator has a computer link instead of a mechanical link or servomechanism between the control station and the manipulator arm. The master arm, which an operator uses to control the manipulator, therefore does not have to resemble the slave arm either kinematically or dynamically. The master arm can be smaller and lighter or larger and heavier than the remote manipulator arm. It can also require a smaller or larger volume in which to move.

In an experimental version of the controller, the master arm is hand-operated. The slave arm has force and torque sensors at the wrist and proximity, touch, and slip sensors at the hand.

The controller hand is located at a control station, which also includes two-dimensional and stereoscopic television displays; graphical displays for proximity, touch, slip, force, and torque information; audio alarms; and control switches. The slave arm is at a remote site that includes a television camera for viewing the manipulator.

The controller uses a distributed microcomputer system for data processing (see



Processing of Data Is Distributed among six microcomputers. Each microcomputer is dedicated to a specific task and communicates with the others at the same station or at the opposite station.

figure). Three microcomputers at the control station are respectively dedicated to control of the feedback mechanisms in the controller hand, operation of the graphical displays, and automatic control of certain functions to ease the burden on the operator. Three microcomputers at the remote station control the slave arm, control the camera, and process the sensor data, respectively. Each microcomputer communicates with the others at the same station through a shared bus and with the microcomputers at the opposite station over a shared input/output channel.

This work was done by Antal K. Bejczy and Sukhan Lee of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 8 on the TSP Request Card. NPO-16470*

Portable Hydraulic Powerpack

This proposed unit would be recharged by chemical energy.

John F. Kennedy Space Center, Florida

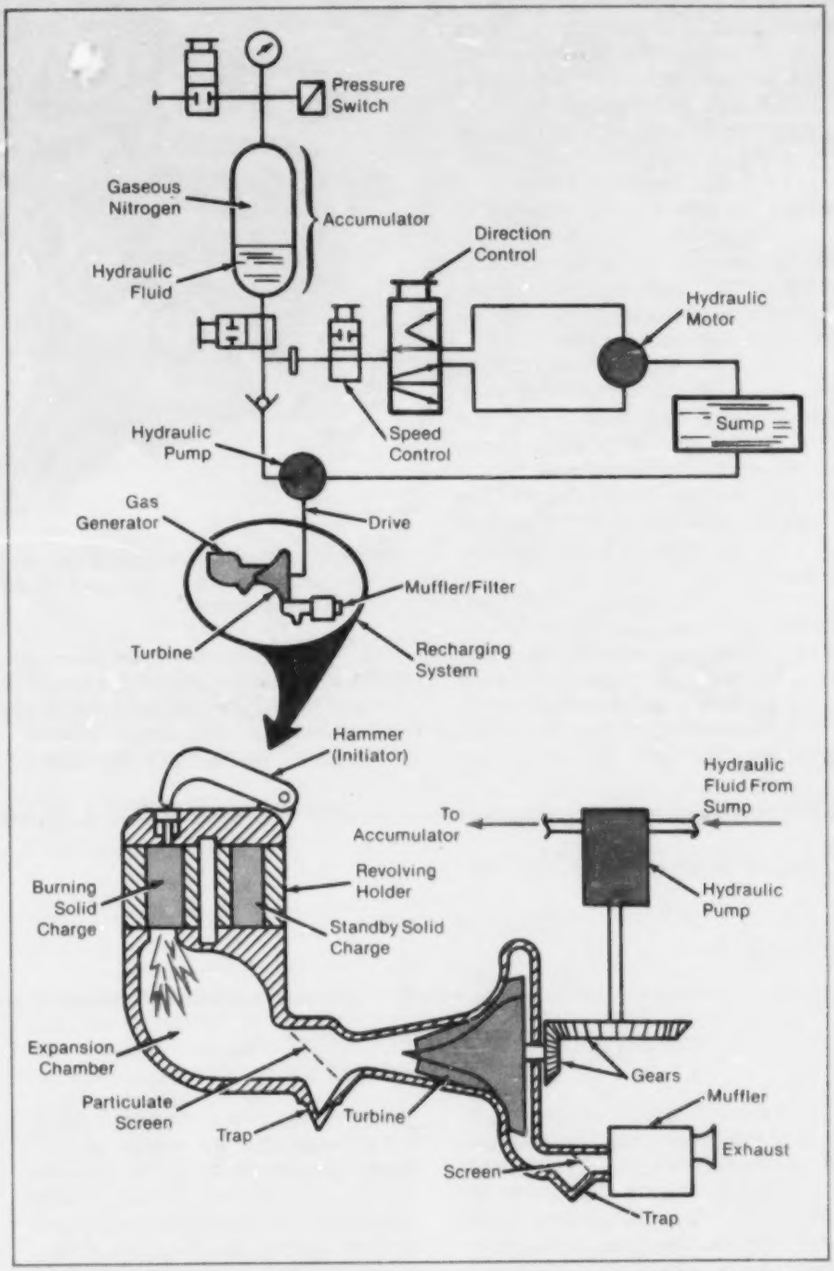
A proposed rechargeable hydraulic powerpack would function as a lightweight, compact source of mechanical energy. The unit could have applications driving wheelchairs and operating drills, winches, and other equipment in remote areas. It could also replace electric motors and internal-combustion engines as a source of power in explosive atmospheres.

The powerpack would employ a slowly burning solid chemical charge to generate hot gas (see figure). The gas would turn the rotor of a turbine, which in turn would drive a pump that would pressurize the hydraulic fluid in an accumulator. The pressurized fluid can then be used on demand to do work — rotating the shaft of a hydraulic motor, for example.

One candidate for the solid charge material is a combination of rubber and ammonium nitrate. This charge is safe and has high energy content in relation to its mass. Its combustion products could easily be filtered to remove objectionable components. A charge composed of sodium azide and copper oxide is also safe and, although its energy content is less, its product gas is nitrogen, which can ordinarily be released directly to the atmosphere.

This work was done by Loren A. Anderson and Rod L. Henry of the University of Central Florida, Otto H. Fedor of Lockheed Corp., and Lester J. Owens of Planning Research Corp. for **Kennedy Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 21]. Refer to KSC-11318.



The **Self-Contained Hydraulic Powerpack** derives its energy from a solid chemical charge. The combustion of the charge would be initiated by a small hammer, and a revolving feeder would replace charges that have been expended. The combustion gases would cool during expansion in the turbine and thus would not be too hot for release to the atmosphere.

Oscillation Damper With Two Spring Rates

Bellows and springs rapidly damp the vibration of a long, slender boom.

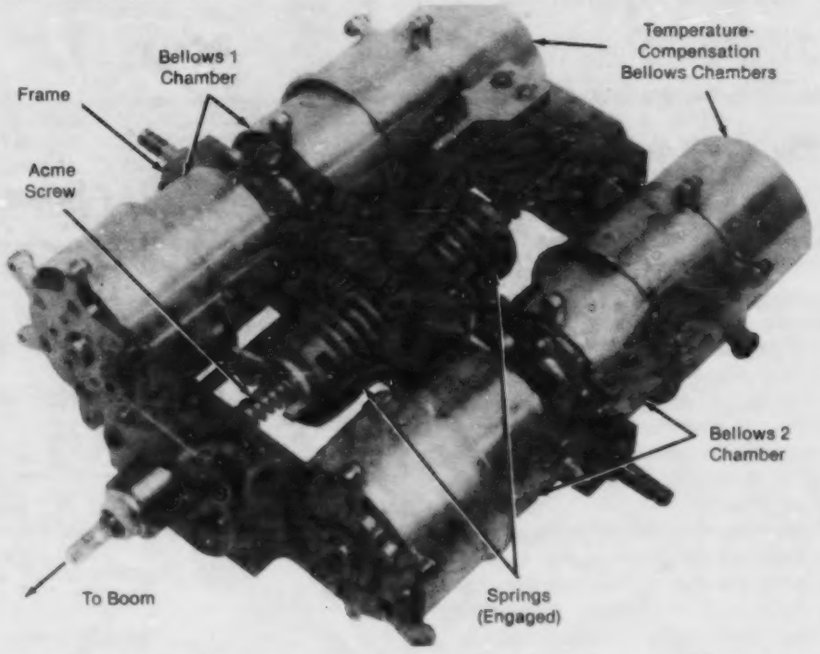
NASA's Jet Propulsion Laboratory, Pasadena, California

Hydraulic damping is used in a device originally developed to stabilize a vibrating structure in space. The mechanism is especially useful for arresting the oscillatory motion of a slender boom with a large mass. On Earth, such configurations arise in the design of masts and cranes.

As shown in the figure, the device has two primary bellows chambers. Each chamber contains hydraulic fluid that is alternately compressed and expanded as the boom oscillates. The fluid flows back and forth through narrow spaces in the center frame. These spaces resist the flow somewhat, absorbing energy from the boom and damping its motion.

A temperature-compensation bellows maintains an approximately constant pressure of fluid in each main bellows. The temperature-compensation bellows communicates with the main bellows through an orifice that allows a small flow of fluid for pressure and volume adjustment but blocks significant oscillation-induced pressure surges.

Normally, the springs are retracted, and the bellows provide spring force. When a higher spring rate is needed, however, a motor (not shown in the figure) turns a pair of acme screws — one a left-hand screw, the other a right-hand screw. The screws drive the springs against the center frame. In that position, the springs assist the bellows to limit the oscillation excursion.



This **Damping Mechanism** will stop the oscillation of an attached boom. Two bellows provide fluid damping. The springs are engaged when extra spring force is required. Otherwise they are retracted.

This work was done by Donald R. Sevilla of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 4 on the TSP Request Card.*
NPO-16223

Dual-Flow-Rate Valve

A flow-control device can be precisely adjusted for two rates.

Lyndon B. Johnson Space Center, Houston, Texas

A valve supplies high-pressure gas at either of two preselected flow rates. The valve is adjustable between 0.12 and 1.2 lb/s (0.054 and 0.54 kg/s) of hydrogen at 3,300 lb/in.^{2} (23 MN/m^2) and 80° F (27° C). The two flow rates can be preadjusted between these limits in increments of 0.01 lb/s (0.0045 kg/s).

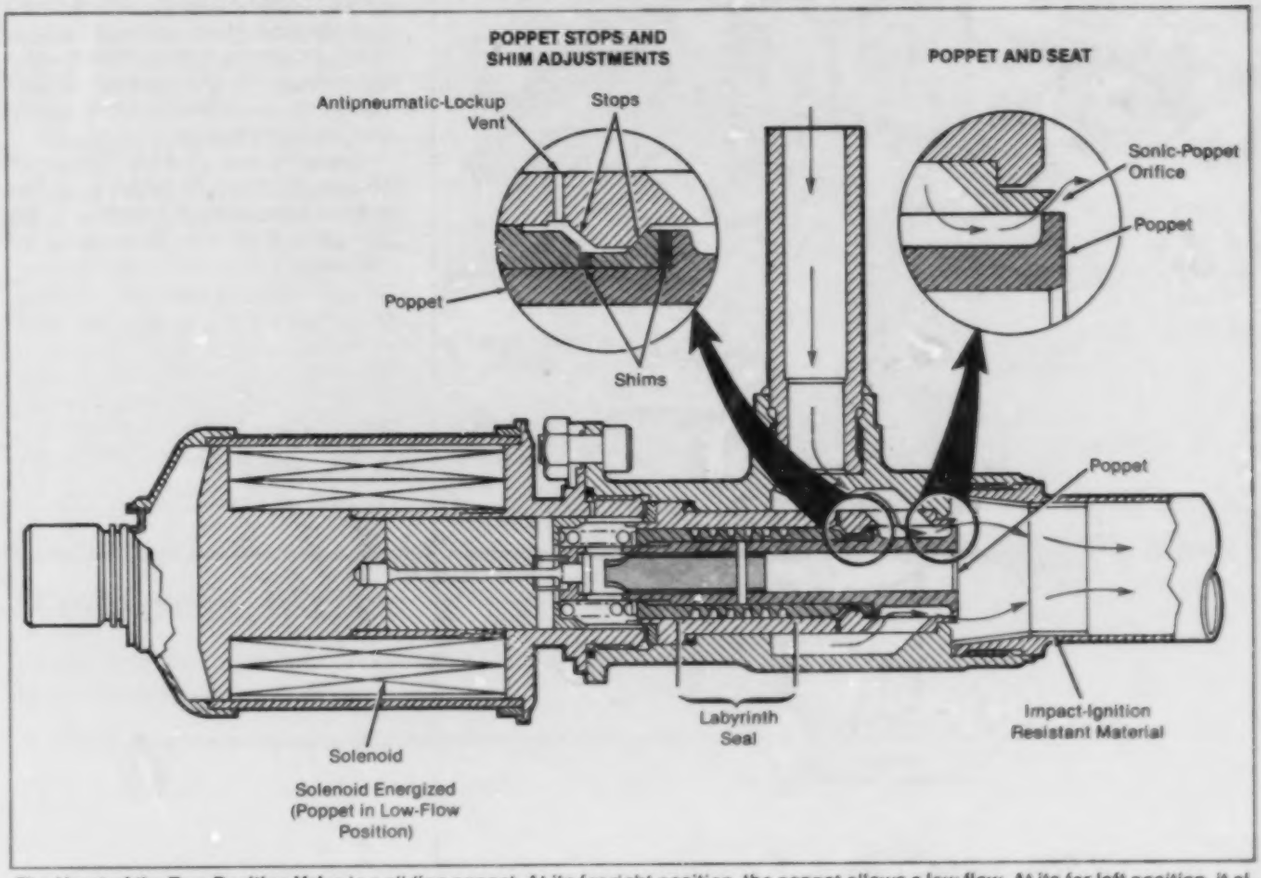
The flow is controlled by a solenoid-operated two-position poppet (see figure). The stroke of the poppet — and therefore the two flow rates — is adjusted by inserting or removing shims to alter the positions of the poppet stops. The mass flow through the valve varies approximately linearly with the poppet travel. The poppet and its sleeve, including the stroke-adjusting shims, is a self-contained assembly that can be calibrated for flow in a fixture and stocked for later use.

The poppet stops are conical so that the poppet nests firmly at the end of each stroke without lateral vibration. The wear of the labyrinth-seal-bearing surfaces is thus minimized.

The gas passes through the poppet orifice at sonic velocity. The surfaces at and near the orifice are at a low angle of attack with respect to the flow to reduce the energy released by the impact of particles entrained in the gas. The interior surface of the pipe adjacent to the valve exit port may be shielded with a material that

resists impacts and ignitions caused by impacts.

This work was done by Richard H. Allbritain of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 53 on the TSP Request Card.*
MSC-20849



The **Heart of the Two-Position Valve** is a sliding poppet. At its far-right position, the poppet allows a low flow. At its far-left position, it allows a high flow.

Rotary Joints With Electrical Connections

Power and data are transmitted on many channels.

NASA's Jet Propulsion Laboratory, Pasadena, California

Two different rotary joints are equipped with electrical connections between the rotating and stationary parts. One joint transmits axial thrust and serves as the interface between the spinning and nonspinning parts of the Galileo spacecraft. The other is a scanning (limited-rotation) joint that aims scientific instruments from the nonspinning part. Selected features of both may be useful to designers of robots, advanced production equipment, and remotely controlled instruments.

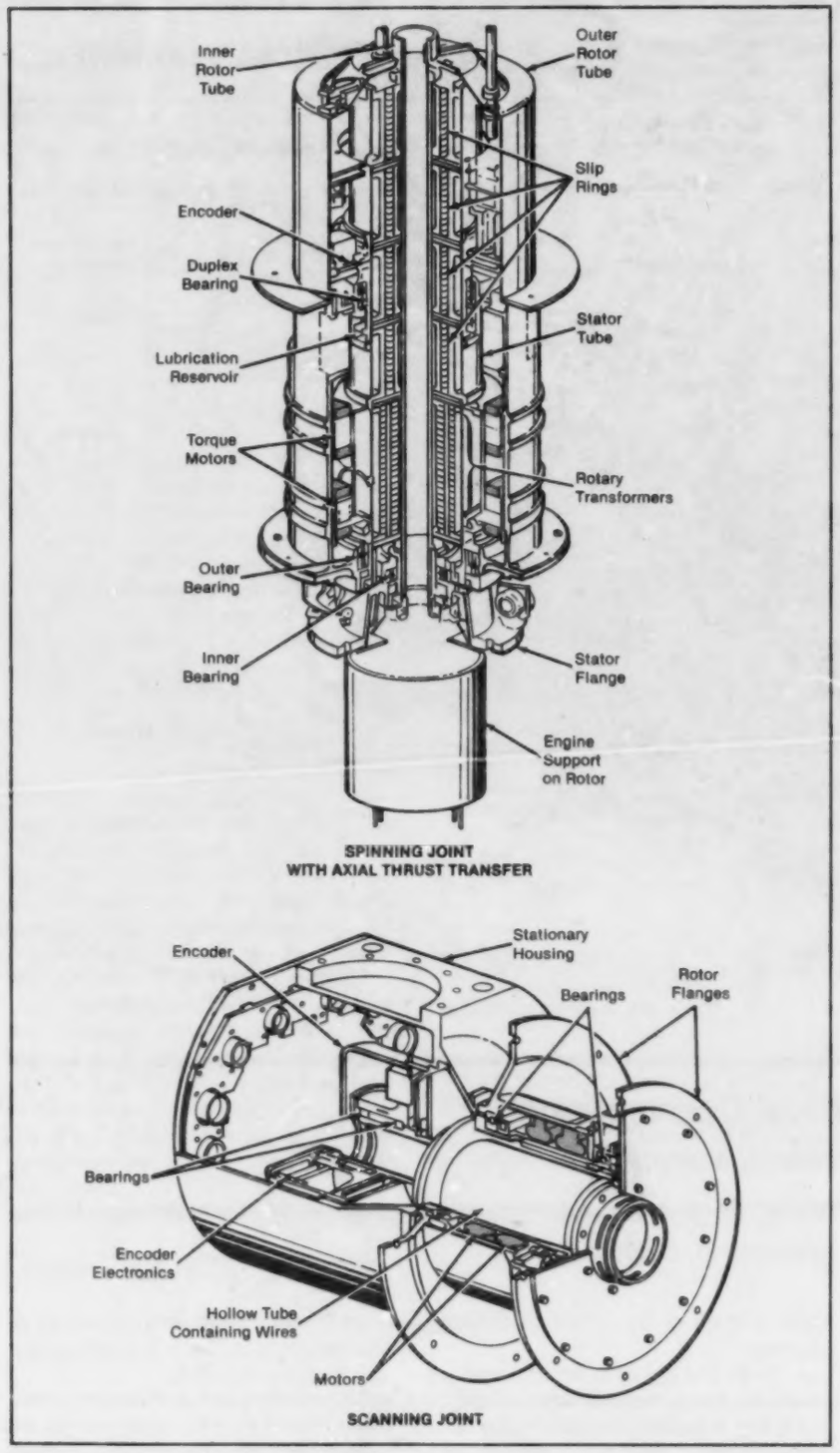
The spinning joint includes a stator tube placed between inner and outer rotor tubes (see figure). The concentricity of the three tubes is enforced by inner and outer bearings at the lower end. The axial thrust is transferred between the rotor and stator by a pair of duplex bearings.

In both the spinning and scanning joints, the torque between the rotor and the stator is supplied by two 24-pole dc torque motors oriented to minimize the magnetic cogging torque and the external magnetic field of the combination. An optical encoder in each joint signals the angular position for rotor pointing and motor commutation. The angular resolution of each encoder is 20 arc-seconds.

In the spinning joint, the inner tube supports the inner halves of a stack of 23 rotary transformers with manganese-zinc ferrite half cores. These transformers are used for data transmission at 800 kb/s. Four slipring modules contain a total of 48 hard-silver sliprings contacted by brushes molded of silver/molybdenum disulfide/graphite. These transmit power and low-frequency data.

The scanning joint is less complicated than the spinning joint. A hollow shaft extending from the housing holds two bearings that support the rotor. The instrument platform is bolted to the rotor flanges. Since the rotation of this joint is limited to 210°, flexing connections can be used. A 200-wire circuit assembly in the hollow shaft transfers signals and power between the rotor and stator. The wires are on four 50-wire tapes, with two wound clockwise and two wound counterclockwise to minimize the spring torque.

The bearings and lubricants are essential to the long-term reliability of the joints. All of the bearings are made with 440C



stainless-steel balls, chromium-alloy rings, and polytetrafluoroethylene ball separators. The bearings are designed with a variety of precise contact angles and preloads. All are pretreated with tricresyl phosphate, then lubricated with a commercial radiation-resistant oil. Each bearing cavity contains an acrylic copolymer lubricant reservoir.

This work was done by Fredrick W. Osborn of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 82 on the TSP Request Card.*
NPO-16250

The **Rotary Joints** are of two types: a spinning joint (above) and a limited-rotation scanning joint (below). The spinning joint contains rotary transformers and sliprings to transmit signals and power. The scanning joint uses flexible wire connections.

Emergency Brake for Tracked Vehicles

A clamping mechanism brings the vehicle to a smooth halt.

Lyndon B. Johnson Space Center, Houston, Texas

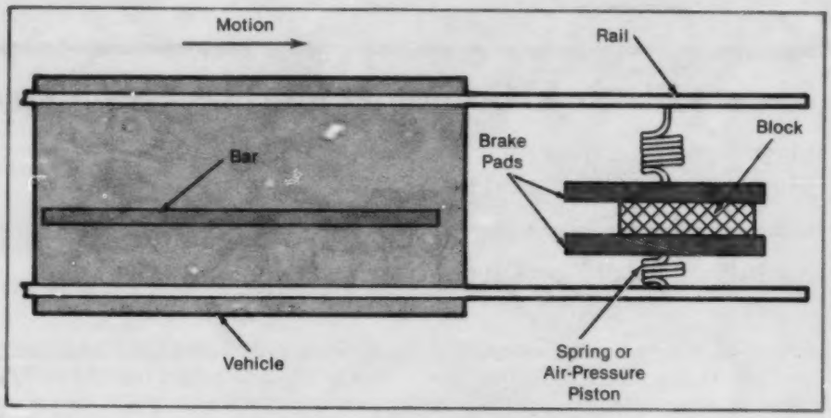
A caliper brake automatically stops a tracked vehicle as the vehicle nears the end of its travel. The mechanism includes two brake pads mounted on the track rails, which engage a bar on the vehicle when it approaches the end of the line. The

emergency-braking system may be suitable for elevators, amusement rides and machine tools.

The brake pads are alined parallel to the rails (see figure) and are continuously energized — by spring or air pressure — so that a spacer block is clamped between the pads.

When the vehicle approaches the brake, the bar dislodges the spacer block. A polytetrafluoroethylene coating on the block enables it to slide easily from between the brake pads. The pads then grip the bar, decelerating the vehicle. A pressure-activated switch on the air-pressure supply or a limit switch on the brake pads, or both, is triggered when the brake operates and sends a signal to cut off the vehicle power.

This work was done by Gary L. Green and Sonne L. Hooper of Pan American World Airways, Inc., for **Johnson Space Center.** *For further information, Circle 22 on the TSP Request Card.*
MSC-20513



A Bar on the Vehicle, traveling to the right, dislodges the block between the brake pads. The pads then press against the bar, slowing the vehicle by friction.

"Curtainless" Window

Liquid flow switches this window from transparency to opacity.

Lyndon B. Johnson Space Center, Houston, Texas

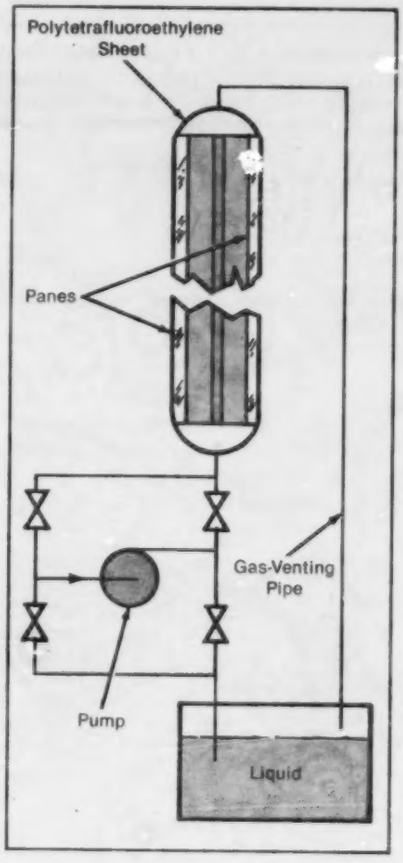
A laminated window is switched from transparency to opacity when liquid is pumped out of the spaces between the lamina. The window is made from panes of glass or plastic, with a sheet of polytetrafluoroethylene centered in the gap between them. The liquid is pumped into and out of the spaces between the sheet and the panes.

With no liquid in the spaces, the window is translucent or opaque (depending on the thickness of the sheet). To make the window transparent, the spaces are filled with liquid from a reservoir. Transparency results when the liquid fills in the surface irregularities of the sheet. When the liquid is pumped out, the window again becomes translucent or opaque.

As indicated in the figure, polytetrafluoroethylene is used for the sheet. At low thickness, it has a milk-white translucency. At high thickness, it is opaque.

The liquid should have a refractive index between 1.30 and 1.40, close to that of polytetrafluoroethylene. Acetone, isopropyl alcohol, or trichlorotrifluoroethane work well.

If the sheet of polytetrafluoroethylene is only 2 to 3 mils (0.05 to 0.08 mm) thick, it can be made transparent by wetting only one of its surfaces. As the sheet thickness increases, however, better results are obtained when both surfaces are wet.



The panes need not be flat. They may be shaped in parallel curves. For decorative purposes, the sheet may be patterned to give alternating dark and light areas in the window.

The pump that fills and empties the voids may be controlled manually. Alternatively, it may be operated by a photoelectric sensor when light entering the window rises above or falls below a preset level.

This work was done by Dale L. Connelly of **Johnson Space Center.** *For further information, Circle 1 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lyndon B. Johnson Space Center [see page 21]. Refer to MSC-18417.

A Pump Transfers Liquid from the reservoir to the window voids. The gas-venting pipe transfers gas to the reservoir when the window is filling and to the window when the window is emptying.

Secure Disposal Container for Classified Papers

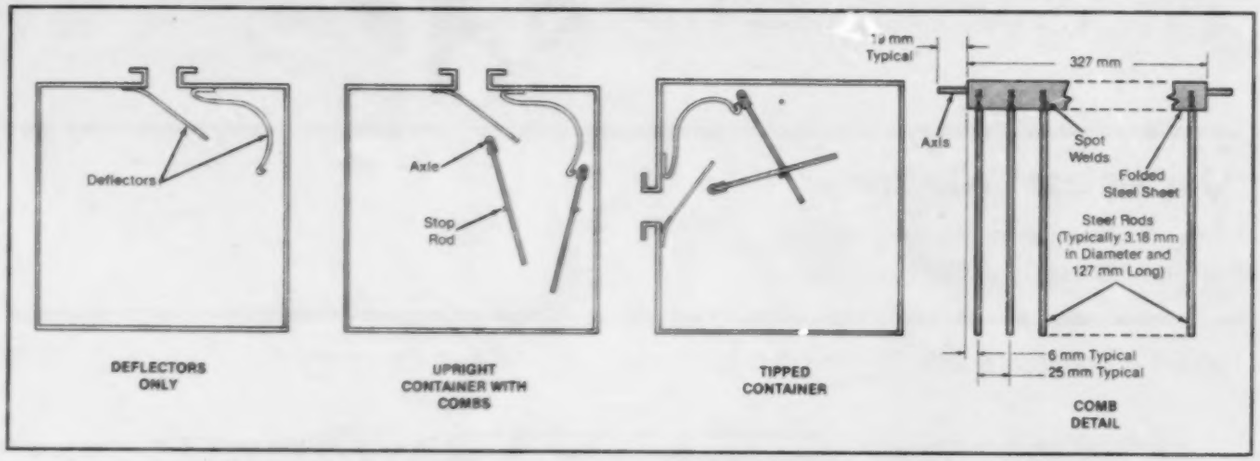
Meshing steel combs retain papers when container is overturned.

NASA's Jet Propulsion Laboratory, Pasadena, California

Deflectors are sometimes installed at the opening of a "secure" disposal container to stop people from reaching into the container and withdrawing discarded documents. If the container is tipped, however, the deflectors may not prevent the refuse from falling out.

One simple solution to this problem is illustrated in the figure. Comblike shutters are installed on hinges near the deflectors. If the container is upright, the combs hang vertically and out of the way. When the container is tipped or overturned, gravity forces one or both of the combs to fall over the opening. When this happens, the teeth intermesh and the container opening is covered, preventing its contents from falling out.

This work was done by Earl R. Collins, Jr., of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 60 on the TSP Request Card.*
NPO-16517



Pivoted Combs Swing to close the opening if the container is tilted by more than a few degrees. The interdigitated combs not only keep paper in the container but also act in combination with the deflectors to prevent the contents from being read through the opening.

Rotating Drive for Electrical-Arc Machining

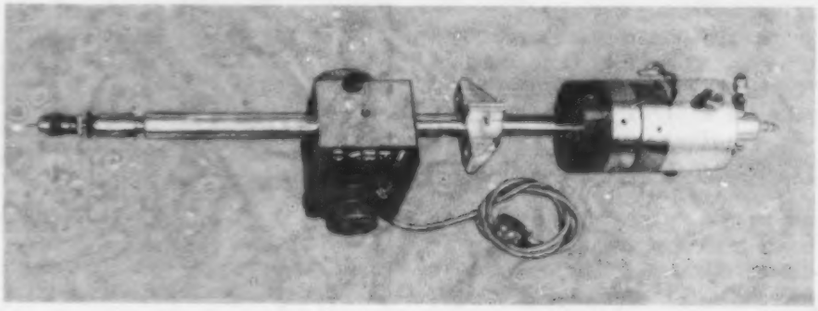
A rotating electrode produces round holes with untapered walls.

Marshall Space Flight Center, Alabama

A rotating drive improves the quality of holes made by electrical-arc machining. The mechanism (Uni-tek, rotary head, or equivalent) is attached to an electrical-arc system. The drive rotates the electrode as though it were a mechanical drill, while an arc disintegrates the metal in the workpiece, thereby creating a hole. The rotating electrode method is often used in electric-discharge machining. This NASA innovation is an application of the technique to electrical-arc machining.

The hole is more nearly round than if there was no rotation. In addition, the hole wall is more nearly parallel to the hole center axis, whereas previously the wall would have had more taper.

This work was done by C. D. Fransen of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-19946



This **Rotary Head** for electrical-arc machining rotates an electrode or workpiece.

Variable-Displacement Hydraulic Drive Unit

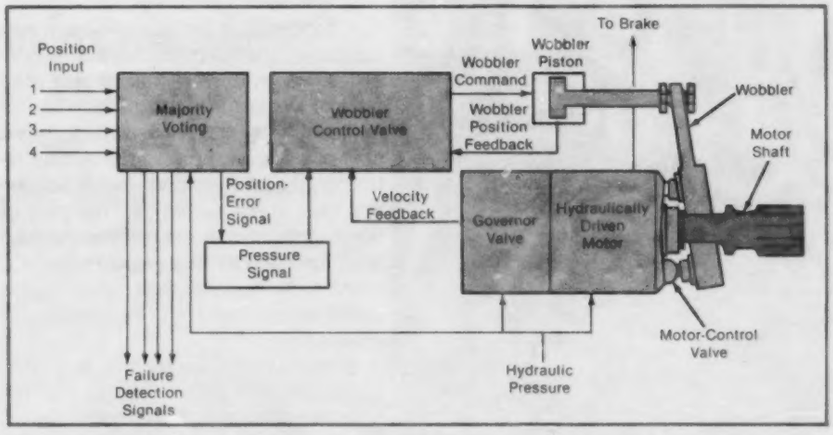
Hydraulic power would be controlled through multiple feedback loops.

Lyndon B. Johnson Space Center, Houston, Texas

In a proposed hydraulic drive unit, the power would be be closely matched to the demand, thereby saving energy. The concept may be applicable to machine tools, aircraft controls, and marine controls.

The concept is illustrated in the figure. The hydraulic flow to and from the motor is adjusted by the motor-control valve connected to the wobbler. The wobbler angle determines the motor-control-valve position, which in turn determines the motor displacement.

The wobbler is controlled by the wobbler piston, which is hydraulically positioned by the wobbler-control valve. Three mechanical feedback loops feed into the wobbler-control valve by the summing of forces: The wobbler position is fed back by a spring force. The motor-shaft velocity is fed back hydraulically through the governor. The external position-command signal is supplied as the pressure analog of an externally-generated electrical position-error signal. This force-summing scheme minimizes backlash by not involving mechanical linkages.



Three Feedback Signals are fed to the wobbler-control valve to match the flow of hydraulic power to the demand.

This work was done by David J. Lang, David J. Linton, and Albert Markunas of Sundstrand Energy Systems for **Johnson Space Center.** *No further information is available.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the Sundstrand Corp., Rockford, IL 61125.

MSC-20728

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Survey of Hand Controllers for Teleoperation

A report surveys handgrip designs, control-input devices, and control strategies.

An 83-page report presents a comprehensive survey of hand-controller technology in three major categories: handgrip design, control-input devices, and control strategies. The approach taken in the review is to identify and describe existing handgrips, control-input devices and control strategies, and new components and techniques that may become elements of advanced hand controllers to satisfy increasing performance requirements for teleoperation in the future.

Fourteen handgrip designs are presented and evaluated relative to four major categories; engineering-development requirements, controllability, human/handle interaction, and human limitations made apparent by the particular handle design. A brief analysis is made of the attributes shared by the most satisfactory handles.

Twelve hand-controller input devices are reviewed and evaluated — each solely on its characteristics and without regard for the control strategy used with the device. The evaluations are given in terms of 17 parameters. (1) task performance, (2) configuration feedback, (3) force feedback, (4) controller/slave correspondence, (5) operating volume, (6) operator workload, (7) human limitations, (8) cross-coupling, (9) singularities, (10) anthropomorphic characteristics, (11) physical complexity, (12) control-implementation complexity, (13) control/display interference, (14) accuracy, (15) technological availability, (16) cost, and (17) reliability.

Twelve general manipulator-control strategies ("control modes") are surveyed and evaluated. Only the modes are considered, but not such specific servo-controls as proportional or pseudoderivative. The control modes have been divided into four primary categories, which are representative of the more successful techniques: rate, unilateral position, bilateral position, and operator-aiding control.

The report concludes by raising a number of questions about the design of handgrips and control-input devices and about teleoperation control strategy and proposes a number of simple, first-phase experiments directed toward the development of empirical design rules for space teleoperator controllers. An extensive list of references supporting the state-of-the-art review is at the end of the report. The references are organized in the order quoted within the text (62 sources) and as a general bibliography of related literature (127 sources).

This work was done by Thurston L. Brooks and Antal K. Bejczy of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "A Survey of Hand Controllers for Teleoperation," Circle 88 on the TSP Request Card.*

NPO-16610

Fabrication Technology

Hardware, Techniques, and Processes

122 Attaching Metal Fasteners to Silica Tiles
123 Compact Plasma Deposition Chamber
123 Lubricating Holes for Corroded Nuts and Bolts
124 Rapid Adhesive Bonding of Composites
125 Solar-Cell-Junction Processing System
126 Leakproof Swaged Joints in Thin-Wall Tubing
127 Detecting Contaminant Particles Acoustically
127 Finding Brazing Voids by Holography
128 Electromagnetic Hammer for Metalworking
135 Forging Oxide-Dispersion-Strengthened Superalloys
136 Acoustic-Emission Weld-Penetration Monitor
136 Holder for Tinning Microcircuit Leads
137 Improvements in Ionized Cluster-Beam Deposition
138 Hermetic Edge Seals for Photovoltaic Modules
138 Television Monitoring System for Welding
139 Wrinkle-Free Hydroforming of Wire Mesh

Attaching Metal Fasteners to Silica Tiles

Stress is distributed so that a high load can be borne.

Lyndon B. Johnson Space Center, Houston, Texas

A bonded-plug method has been successful in attaching mechanical fasteners to porous silica refractory tiles used on the outer surface of the Space Shuttle orbiter. A fastener is bonded in a densified hole or captured in a plug of similar refractory material, which in turn is bonded in a hole in the parent tile. The plug or bonding distributes the mechanical load from the fastener to a broad region surrounding the fastener, thus reducing local stress concentration and the likelihood of breakage.

In the bonded-plug technique, a blind hole is drilled in a silica tile with a bit thirteen sixty-fourths inch (5.2 mm) in diameter. A heating coil at a temperature of 1,000° F (538° C) is inserted in the hole for 7 minutes to drive off waterproofing compound to a depth of about one-eighth inch (3.2 mm) around the hole wall.

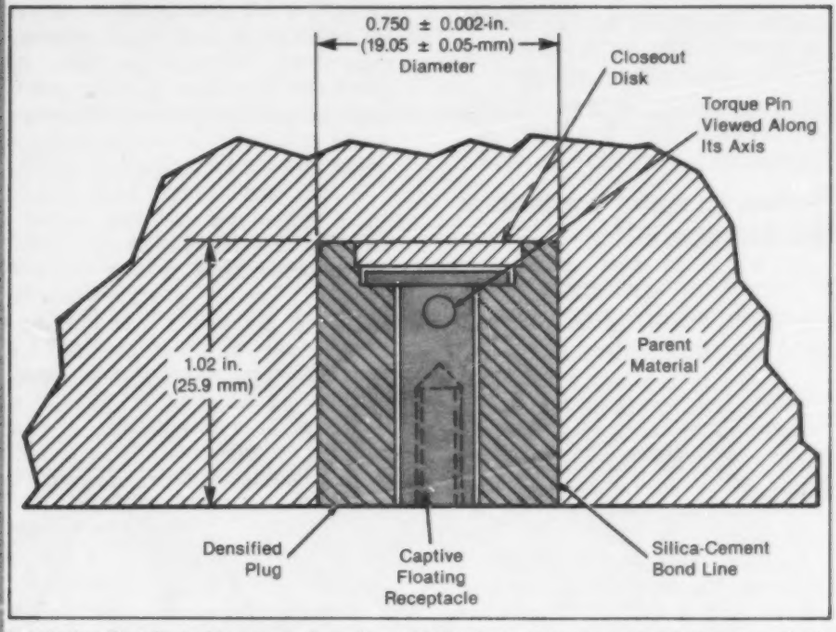
The hole is then ready for densification. Colloidal silica is poured in the hole and allowed to stand for 5 minutes. During this time, the tile around the hole absorbs silica from the colloidal liquid. The colloidal silica is drawn off with an eyedropper. The hole is air-dried for half an hour and then dried under heat lamps at 250° ±25° F (121° ±14° C) for a full hour.

This densification procedure is repeated. The density of the hole wall is then 40 to 50 lb/ft^3 (640 to 800 kg/m^3), as compared with 22 lb/ft^3 (352 kg/m^3) for the bulk of the tile. Thus, the hole wall can support a greater load density than it could before densification.

A nickel-alloy insert with external and internal threads is screwed into the hole. Silica cement is injected into the inner end of the hole to a depth of one-sixteenth inch (1.6 mm) and air-dried for 24 hours to lock the insert in position. The tile can then sustain tensile loads on the insert of 29 to 45 pounds (129 to 200 N) at 1,400° F (760° C).

In the configuration shown in the figure, a floating fastener adjusts to misalinement. Load is transmitted from the fastener to the plug to the tile, the load at each interface being distributed over a larger area.

The plug is machined from 22-lb/ft^3 (352-kg/m^3) silica (the same material as that used for the tile). It is heat-cleaned in an oven at 1,600° F (871° C) for one-half hour. It is dipped in colloidal silica for 5 minutes. It



Loads Are Distributed in stages from the receptacle and the torque pin to the densified plug to the parent material. The bearing area increases at each stage.

is dried in ambient air for one-half hour, then oven-dried at 265° F (129° C) for 1 hour. Dipping and drying are then repeated. The density of the silica plug is then 40 to 50 lb/ft^3 (640 to 800 kg/m^3).

An internally threaded receptacle, a torque pin, and a closeout disk are inserted in the plug. The plug is bonded with silica cement in a mating hole in a tile. The receptacle floats in the tile and can accommodate lateral misalinement of ±0.03 in. (0.76 mm) and azimuthal misalinement of a few degrees. The tile can sustain torque loads of 60 to 90 pound-inches (6.8 to 10.2 N-m) and tensile loads of 184 to 263 pounds (532 to 818 N) on the fastener at 1,400° F (760° C).

This work was done by Jack W. Holt, Stanley Y. Yoshino, and Laurence W. Smiser of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 67 on the TSP Request Card.*
MSC-20537

Compact Plasma Deposition Chamber

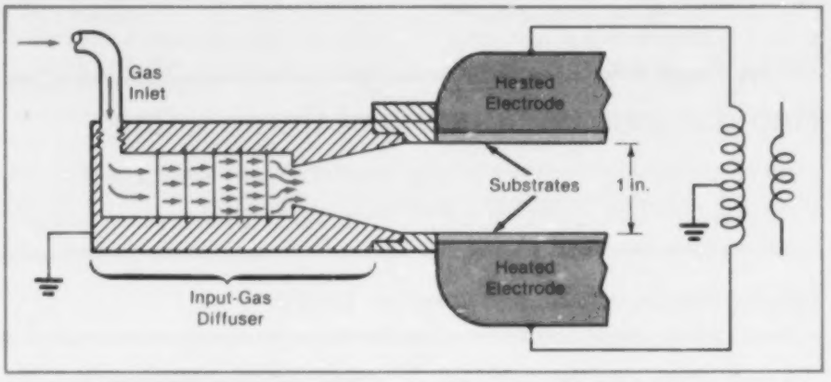
Contamination and nonuniformity should be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

Substrates serve as the walls of the deposition chamber in a proposed configuration for plasma deposition of amorphous silicon. The new design reduces the requirements on chamber size and is expected to increase product quality.

In a typical glow-discharge plasma deposition process, the deposition substrates are placed on electrodes in a relatively large chamber. Since one electrode is grounded to the chamber walls, there is an electrical imbalance that favors deposition on one substrate. Also, because the chamber surfaces are an order of magnitude larger than the substrates, they both collect and emit contamination.

In the new deisgn (see figure), with the substrates forming the two largest chamber walls, the electrical imbalance and contamination-source area would be reduced. The substrate walls will be 15 in. (38.1 cm) square and held 1 in. (2.54 cm) apart. The closeness of these walls is expected to contribute to purity by permitting the rapid flushing of gases. The exhaust diffuser is opposite the gas-inlet diffuser. Concave side walls close the 15 in. (38.1 cm) long by 1 in. (2.54 cm) high space between the diffusers.



The **Deposition Substrates** serve as the two largest chamber walls. The new chamber is intended for the production of amorphous silicon solar cells.

This work was done by Donald B. Bickler of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 5 on the TSP Request Card.*
NPO-16469

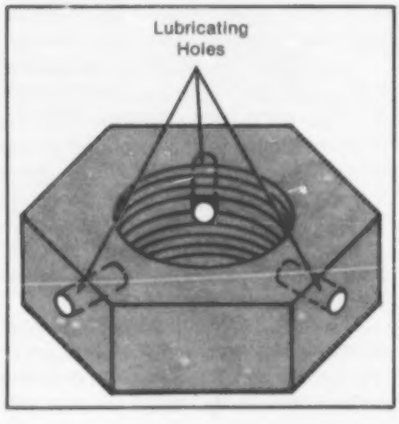
Lubricating Holes for Corroded Nuts and Bolts

Corroded fasteners are taken apart more easily.

Marshall Space Flight Center, Alabama

The removal of a nut rusted onto a bolt is made easier by boring small holes from three of the flats through to the thread (see figure) before the nut is used. The holes make it possible to apply lubricants and rust removers directly to more of the thread than would otherwise be reachable.

The lubricating-hole concept was tested in an experiment. Twenty 3/8-in.-24 thread carbon-steel bolts were placed in 20 holes in an aluminum plate. Fifteen nuts were modified with lubricating holes 3/32 in. (2.38 mm) in diameter, while five were used unmodified. All the nuts and bolts were swabbed with sea-



Lubricating Holes are bored to the thread from three of the flats. The holes facilitate the application of penetrating oil to help loosen the nut when it is rusted onto a bolt.

water, then assembled into the plate with washers and tightened to a torque of 20 lb-ft (27 N-m). The holes of five of the modified nuts were covered with temperature-resistant tape.

The assembly was placed in a convection oven at 90° C. At 24-hour intervals, more seawater was poured over the joints. The assembly was removed from the oven after 54 hours. After the assembly cooled to room temperature, the tape was removed. The nuts were sprayed with a commercial all-purpose lubricant, which was allowed to soak in for 30 seconds.

The amount of torque required to loosen each nut was measured (see table). The modified nuts required less torque than the others; this shows that the holes allow the lubricant to flow more effectively into the threaded joints. The table also shows that there is no advantage in covering the holes in a seawater environment. It may, however, be advantageous to cover the holes in the presence of particles, dusts, or powders.

Nut Condition	Loosening Torque, lb-ft					Average
No Holes	27	27	25	27	29	27
Modified	20	20	20	21	20	19.7
Modified	18	20	18	20	20	
Modified (Hole Covered)	20	20	20	20	20	20

Torques Required To Loosen nuts from bolts were measured after exposure to a corrosive seawater environment, followed by lubrication. In all cases, more torque was required to remove the nuts that did not have lubricating holes.

This work was done by Benjamin G. Penn, Jonny M. Clemons, and Frank E. Ledbetter III of **Marshall Space Flight Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 21]. Refer to MFS-28086.

Rapid Adhesive Bonding of Composites

Strong bonds are created in less time and with less power than if conventional bonding methods were used.

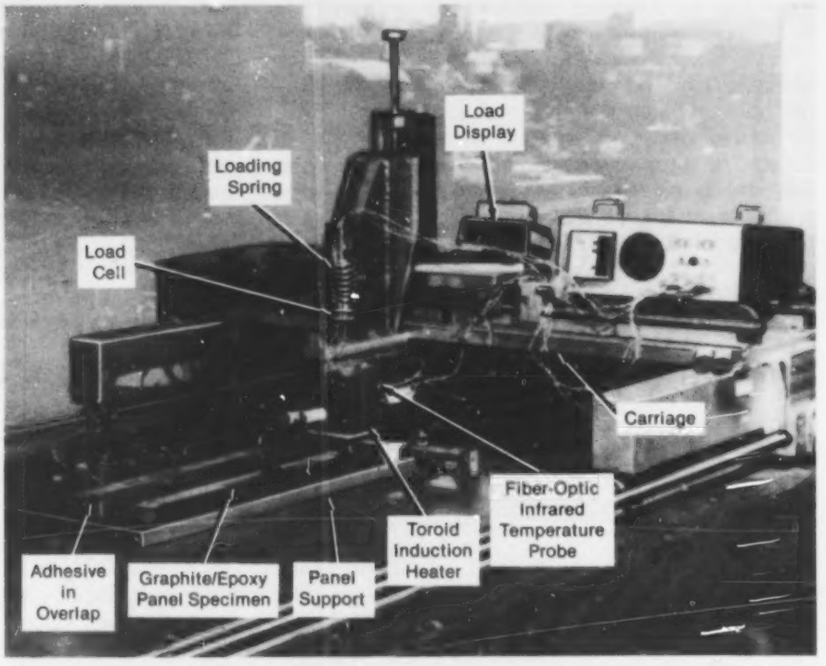
Langley Research Center, Hampton, Virginia

A rapid adhesive bonding (RAB) technique for composites uses high-frequency induction heating toroids to quickly heat a metallic susceptor impregnated with a thermoplastic adhesive or sandwiched between thermoset or thermoplastic adhesive cloths or films. The susceptor can be a steel screen or a perforated steel foil.

For lap-shear panel assembles, the susceptor and adhesives are placed between the fiber-reinforced-plastic composite-materials to be bonded and the assembly is placed in a fixture on a machine bed. The toroids are attached to the machine carriage in such a way that a continuous uniform load is applied to the assembly under the toroid units as they pass over it. Power to the toroid heads is applied before the carriage begins its traverse of the assembly.

The toroids rapidly heat the adhesive to the bonding temperature as they pass over it. These conditions are maintained for one to several minutes to promote adherend/adhesive wetting and to effect cross-linking (cure) in thermosetting adhesives as the toroids pass each spot in the adhesive bond. After the toroids pass, the bond area rapidly cools to a temperature below which the adhesive is rigid.

The RAB equipment for overlap panel assemblies is shown in the photograph. The toroid induction heaters are mounted with a load cell on a support structure that is mounted on a transverse alinement slide. That slide is located on a longitudinal traversing carriage, which travels along a standard machine bed. The power supply, power control, and load indicators are on the transverse slide. Thermocouple and infrared sensors monitor the panel assembly temperatures.



The **RAB Apparatus Uses Toroid Induction Heaters** with metallic susceptors for adhesive bonding.

The panels to be bonded, 2 ft (0.61 m) long in the photograph, are located on an

insulated panel support. Polytetrafluoroethylene boots are mounted on the bases of the toroids to enable them to slide smoothly across the surface of the parts to be bonded. The power supply, which draws approximately 300 W or less at 60 Hz and 120 V for each toroid, provides the energy for a self-tuning induction-heating circuit that operates at 30,000 to 100,000 Hz. Metallic susceptors concentrate the heat in the bond line.

Monitoring instrumentation verifies selected levels of bonding pressure and temperature. Bonding pressure is applied through the toroid head via a loading spring controlled by a manual adjustment and monitored by the load cell and its readout display. Temperature monitoring in the adhesive bond line is an important requirement of the RAB process. A commercially available fiber-optic infrared temperature probe that can monitor a very small region of the bond line from the edge of the bond is used with a special alinement feature to provide the required feedback signal.

Lap-shear specimens cut from a graphite/epoxy panel bonded with an epoxy/phenolic adhesive were tested at room temperature (RT) and at 180° F (82° C) as bonded, at RT and 180° F after 1,000 thermal cycles from −100° F (−73° C) to +180° F, and at RT and 180° F after a 72 h boiling-water exposure. The as-bonded specimens averaged 3,940 psi (2.72×10^7 N/m^2) lap-shear strength (LSS) at RT and 3,200 psi (2.21×10^7 N/m^2) at 180° F compared with 2,940 and 2,970 psi (2.03 and 2.05×10^7 N/m^2), respectively, for similar specimens fabricated by standard press bonding.

After thermal cycling, the RAB specimens averaged 3,640 psi LSS at RT and 3,200 psi at 180° F compared with 2,970 and 3,140 psi (2.04 and 2.16×10^7 N/m^2), respectively, for standard press specimens. Therefore, the RAB process has no degrading effect on specimen shear strength compared to standard bonding, and thermal cycling does not significantly degrade these properties. The exposure to boiling water degraded bond strengths about 35 percent at RT and 28 percent at 180° F. This degradation matches that noted for the adhesive in the adhesive supplier's literature.

Successful tests were made with other materials including titanium alloy panels. Panels or structures of other geometries can be bonded by the RAB process. Examples are stiffeners or stringers on panels and repair patches. Simple fixtures would have to be designed to hold the specific geometries in place during the RAB procedure.

The type of adhesive bonding of metallic and fiber-reinforced-plastic composite structural components provided by the RAB process is particularly important because load transfer paths through mechanical fasteners, such as rivets or bolts, can cause local overloads and damage in the relatively brittle composites. "State-of-the-art" bonding with aerospace adhesives usually involves the application of heat and pressure in hydraulic presses or autoclaves. The RAB method, in contrast, is similar to spot or seam welding or seam diffusion bonding of aluminum or titanium alloy sheet.

This work was done by Bland A. Stein, James R. Tyeryar, Robert L. Fox, S. Elmo Sterling, Jr., John D. Buckley, Spencer V. Inge, Jr., Linwood G. Burcher, and Robert E. Wright, Jr., of **Langley Research Center.** *Further information may be found in NASA TM-86256 [N84-29968/NSP], "Rapid Adhesive Bonding Concepts" [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, [see page 21]. Refer to LAR-13277.

Solar-Cell-Junction Processing System

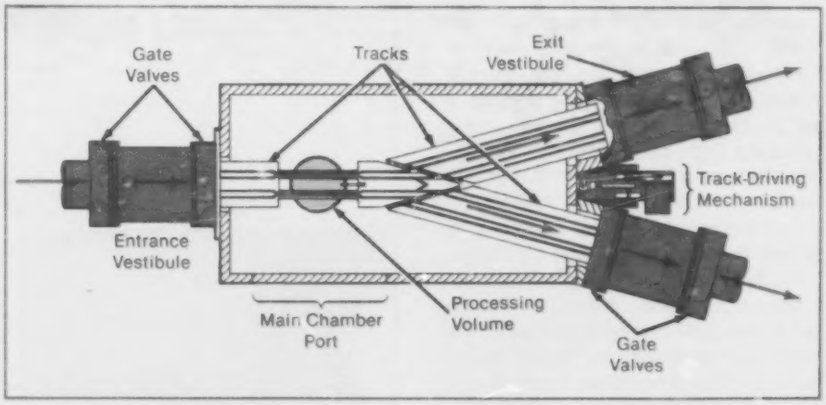
A system under development should reduce equipment costs.

NASA's Jet Propulsion Laboratory, Pasadena, California

A processing system under development will produce solar-cell junctions on 4 in. (10.2 cm) round silicon wafers at the rate of 10^7 per year. The system (see figure) includes a non-mass-analyzed ion implanter, a microcomputer-controlled, pulsed-electron-beam annealer, and a wafer-transport system with vacuum interlock.

In a conventional ion implanter, the dopant phosphorus ions are focused into a beam, which is sent through a magnetic field to remove contaminant ion species having a different charge-to-mass ratio. The beam is then scanned across the wafer on two axes to make a uniform dose.

In the new ion implanter, phosphorus ions are accelerated to 10 keV in a broad, nearly uniform beam that covers the entire wafer. No magnetic beam analysis is used, and the beam is defocused and centered but not scanned: These features eliminate the large, expensive magnet and the plates, circuitry, and power source otherwise needed for scanning. In preliminary tests, solar cells produced without beam analysis performed as well as conventional cells.



The **Solar-Cell-Junction Processing System** includes an ion implanter, an electron-beam annealer (not shown) in the processing volume, and a wafer-transport system with alternating vacuum locks.

A single pulse of electrons covering the entire wafer is used to anneal the damage caused by ion implantation. A

magnetic field to stabilize the beam is generated in an external coil and carried by a yoke to iron columns that guide it to the processing volume in the vacuum chamber. The energy for the pulse is stored in 12 high-voltage dielectric lines, each having a capacitance 2.9 nF and an inductance of 14.2 nH. The lines are joined in parallel to the trigger switch that connects them to the beam-generating diode.

The wafer-transport system is of the walking-beam variety. The wafers ride on rails that oscillate in elliptical orbits. Several pairs of rails are out of phase with each other by an amount that results in a three-phase motion: A wafer is lifted, moved forward a small distance, and dropped onto the next rising rail pair. The wafer speed along the track is 4 in./s (10.2 cm/s).

The track-driving mechanism is located outside the vacuum. To maintain a high production rate, at least two vacuum-feed locks are needed, so that one lock can dispense or receive wafers while the other cycles between the atmosphere and the vacuum. A Y-track switching mechanism directs the wafers along the track to one or the other lock.

This work was done by Stephen N. Bunker and Anthony J. Armini of Spire Corporation for **NASA's Jet Propulsion Laboratory.** *For further information, Circle* **28** *on the TSP Request Card.*
NPO-16540

Leakproof Swaged Joints in Thin-Wall Tubing

Tubular inserts reinforce the joints, reducing the incidence of leaks.

Lyndon B. Johnson Space Center, Houston, Texas

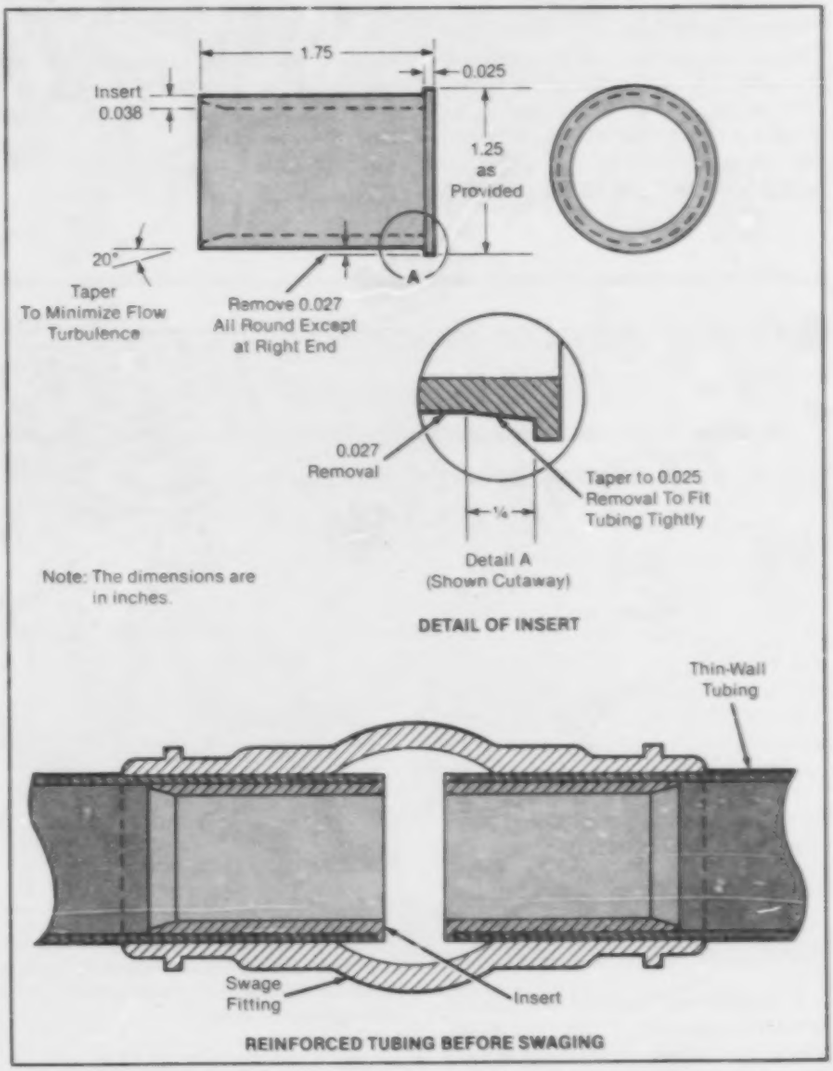
Improved swaged joints in thin-wall tubing are obtained by inserting reinforcing wall thickeners in the sections to be joined. The reinforcing technique was developed for thin-wall tubing in the Space Shuttle hydraulics, and swaging has yielded poor results with such tubing. When the tube diameter is about 1 in. (2.5 cm) or more and the wall thickness is about 0.03 in. (0.76 mm) — approximately half the conventional thickness — swaged joints often leak and have to be reswaged or cut out and replaced.

In the new swaging technique, tubular inserts are placed inside the ends of both tubes to be joined (see figure). Made from thicker-wall tubing with an outside diameter that matches the inside diameter of the thin tubing to be swaged, the inserts support the tube ends at the joint. They ensure more uniform contact between the swage fitting and the tubing.

Most of the outer surface of the insert tube is removed until the outside diameter of this portion is smaller than the inside diameter of the thin-wall tube. A small lip of the full tubing thickness is left at the outer end of the insert as to aid in positioning it and to prevent it from sliding into the tube, away from the swaging area. A short portion of the insert near the lip is slightly tapered so that it fits snugly in the tubing.

The inner end of the insert is chamfered to reduce turbulence in the fluid flowing past it. Although the fitting decreases the inside diameter slightly at the joint, the effect on the flow is negligible. In fact, the fitting introduces less turbulence than a poor conventionally swaged joint.

Joints made by the new method were compared to conventional swaged joints in pressure tests. All joints were made of thin-wall tubing 1.25 in. (3.18 cm) in diameter. Conventionally swaged joints started leaking at 2,600 psi (18 MN/m^2). The joints with inserts, on the other hand, had still not



A Swage Fitting Surrounds a Joint while tubular inserts lend extra support to the tubing to be joined. By ensuring close, uniform contact between the fitting and the tubing, the inserts help to reduce leakage in the finished part. The new swaging technique was developed for Al/Ti/V-alloy hydraulic supply lines.

leaked at 5,100 psi (35 MN/m^2).

This work was done by Fred H. Stuckenberg and L. K. Crockett of Rockwell International Corp. and W. E. Snyder of Deutsch Co. for **Johnson Space Center.** *For further information, Circle 35 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 21]. Refer to MSC-20882.

Detecting Contaminant Particles Acoustically

An apparatus would "listen" for particles in the interior of complex turbomachinery.

Marshall Space Flight Center, Alabama

A proposed acoustic-resonance technique would detect such particles as machining chips in turbopumps or other machinery without disassembly of the machinery. The technique would be used after flushing with high-pressure water and inspecting with a borescope; it would reveal the presence of contaminating particles that remained after the flushing and escaped detection with the borescope.

Contact microphones would be attached at several points on the pump housing. An acoustic transducer would also be attached to the housing to excite the entire pump with sound. The frequency of the sound would be slowly raised until the pump resonates. The microphones would then detect the noise of loose particles scraping against the pump parts.

The microphone outputs would be high-pass filtered to remove the excitation frequency. The higher frequency signals that remain would represent particle noise and would be processed and analyzed. The characteristics of the signals would reveal the locations and quantities of particles and perhaps even the nature of the particle materials.

This work was done by Lynn M. Wyett of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 21]. Refer to MFS-29078.

Finding Brazing Voids by Holography

Vibration-induced interference fringes reveal locations of defects.

Lyndon B. Johnson Space Center, Houston, Texas

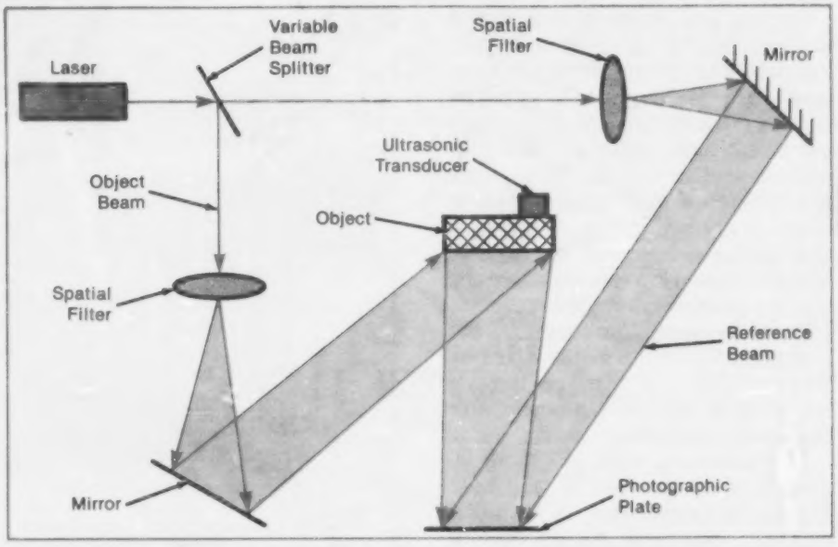
A holographic technique locates small voids in large brazed joints. The technique identifies unbrazed regions 1 in.^{2} (6 cm^2) or less in area.

An ultrasonic transducer is clamped on the object, which is then placed on an optical table for holographic evaluation (see figure). Without acoustic excitation, the object is illuminated by the object beam from the laser, while the reflected object beam and the reference beam are recorded on a photographic plate.

After the plate has been developed, the operator replaces it and views the object through it. He or she energizes the acoustic transducer and looks for optical-interference fringes, which indicate voids. The acoustic excitation frequency is adjusted between 50 and 300 kHz to vary the positions of vibration nodes and antinodes until the vibrational mode gives rise to a set of fringes that most clearly show the defects sought. The plate then is removed, and a new one is exposed to record the defect pattern.

This work was done by Richard Galluccio of United Technologies Corp. for **Johnson Space Center.** *For further information, Circle 44 on the TSP Request Card.*

MSC-20495



A Holographic Apparatus is used to view the object while it is vibrated ultrasonically. Interference fringes in the hologram reveal brazing defects.

Electromagnetic Hammer for Metalworking

High eddy currents apply pressure for cold-forming.

Marshall Space Flight Center, Alabama

An electromagnetic hammer exerts momentary high pressure over a small area of a metal workpiece. In contrast with mechanical hammers, the electromagnetic hammer requires no dynamic material contact with the workpiece; consequently, it produces almost no change in the metal grain structure.

The principal elements of the hammer system are an energy-storage capacitor, a switching device, and a work coil. The capacitor is charged to a predetermined voltage, then rapidly discharged by the switching device into the coil. The current in the coil produces an intense, rapidly-changing magnetic field, which induces eddy currents in the part of the workpiece facing the coil.

The magnetic repulsion between the eddy currents and the currents in the coil is enough to deform the metal. In one version of the hammer designed for use on an aluminum tank, the currents generate pressures up to 5×10^4 psi (3.4×10^8 N/m^2), which can deform the aluminum as fast as 300 m/s. The repulsive force also acts on the coil, causing it to kick back. The coil is therefore mounted in a holder (see Figure 1) that allows for this motion and makes it possible to reposition the coil simply by sliding it back toward the workpiece.

The coil (see Figure 2) is a spirally wound conductor of beryllium copper with polytetrafluoroethylene spacers between the turns. The most difficult part of fabrication is potting the coil in its housing with a heat-curing, electrical-grade polyurethane material without forming bubbles between the coil turns or in other places where insulation is essential. To minimize air entrapment, the material must be exposed to a vacuum before and after mixing, then fed into the preheated coil under pressure. After potting, the coil is inspected to insure that any bubbles between the turns or on the coil face are too small to degrade performance or shorten the useful life.

This work was done by Shirley A. Anderson, F. Brunet, A. Dowd, R. Durham, J. Ezell, G. Gorr, D. Hartley, F. Jackson, J. Marchand, W. MacFarlane, P. Nameth, K. O'Kelly, H. Phillips, J. Rollo, E. Rupert, H. Sykes, E. Vitrano, and M. Woods of Martin Marietta Corp. for **Marshall Space Flight Center.** *For further information, Circle 66 on the TSP Request Card. MFS-27096*

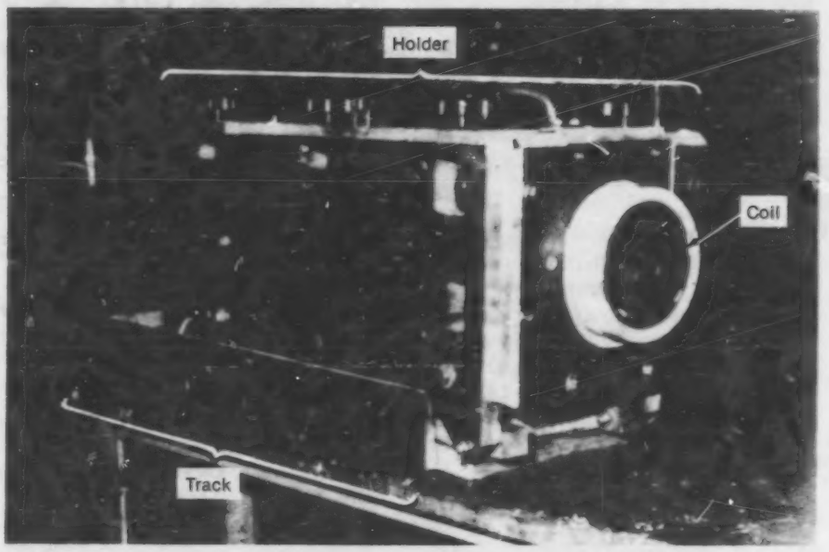


Figure 1. The **Coil Face Protrudes** from the sliding toolholder. When activated, the hammer recoils along the short track.

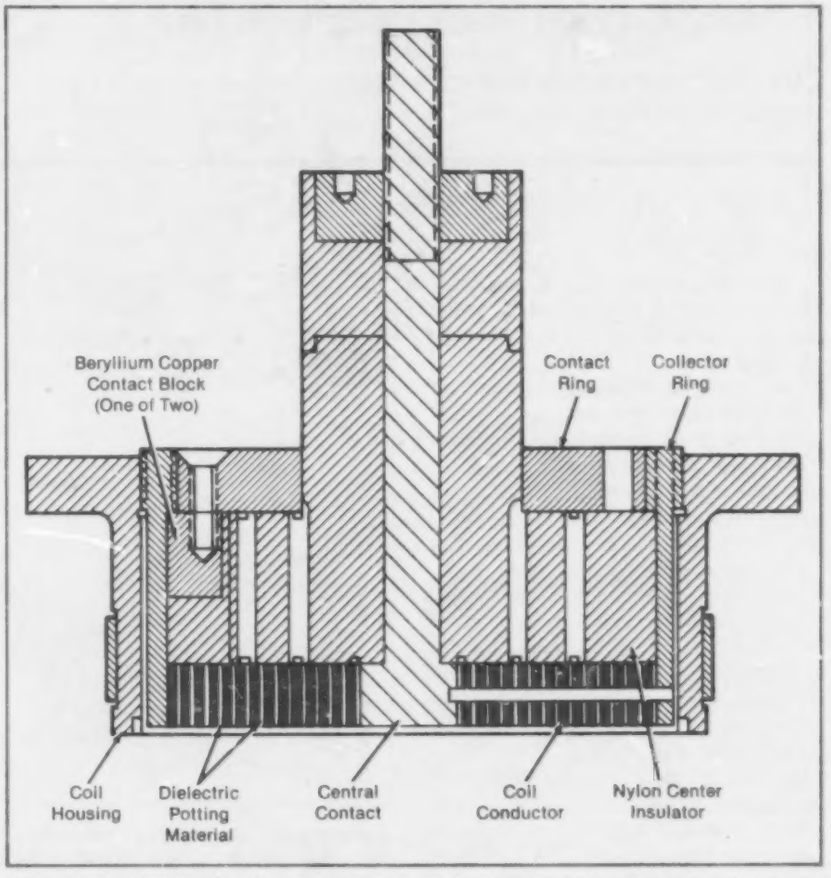


Figure 2. The **Coil Housing** is constructed for mechanical strength to hold the coil against the magnetic force, to maintain electrical contact with the coil ends, and to maintain insulation between coil turns. The drilled holes are placed to facilitate the release of bubbles during potting.

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Forging Oxide-Dispersion-Strengthened Superalloys

A cladding of mild steel prevents surface cracking when the alloy contacts the die.

Lewis Research Center, Cleveland, Ohio

There is a continual need for improvements in the properties of alloys capable of withstanding elevated temperatures. This can be accomplished by using oxide-dispersion-strengthened superalloys such as Inconel® Alloy MA 6000. This alloy is made from mechanically alloyed powders, extruded, hot-rolled into bar stock, and directionally recrystallized. Its microstructure consists of large grains, greatly elongated in the rolling direction. Its properties combine typical superalloy strength at intermediate temperatures [about 1,400° F (760° C)] with superior strength at high temperatures [about 2,000° F (1,100° C)] and make it attractive for turbine-blade applications (see figure).

However, with directionally recrystallized material, it is necessary to machine turbine blades from bar stock, which results in much waste of a quite expensive material. Attempts to forge the fully processed material resulted in a nonreversible loss of mechanical properties.

An approach was therefore developed to take advantage of the ultrafine-grained microstructure of MA 6000 by forging it in the unrecrystallized state. To accomplish this, it was necessary to prevent surface cracking of the material by thermal shock when it came in contact with the forging dies. This was achieved by encasing the alloy in an adherent cladding of mild steel as provided by the original extrusion can or a thick plating. These clad-forging blanks were then coated with a commercial glass lubricant.

A forging temperature between 1,850° and 1,950° F (1,010° and 1,065° C) yields the proper elongated grain structure in the subsequent directional recrystallization heat treatment. The deformation level is not critical. The die design must allow for the additional thickness of the cladding and should avoid sharp transition areas to promote the formation of a continuous elongated grain structure during recrystallization.

FORGED ODS TURBINE BLADE BLANK

GRAIN STRUCTURE OF ODS TURBINE BLADE

Turbine Blades can be strengthened for high-temperature performance by use of forged oxide-dispersion-strengthened (ODS) superalloys. An ODS turbine-blade blank is shown on the left; the grain structure of the ODS turbine blank is shown on the right.

The elevated tensile properties of the forged alloy equal those of the hot-rolled MA 6000 bar. The stress-rupture properties are somewhat lower than those of the bar stock but, at 1,100° C, exceed those of the strongest commercial single crystal, directionally solidified and conventionally cast superalloys.

(Inconel® is a registered trademark of the Inco family of companies.)

This work was done by F. H. Harf and T. K. Glasgow of **Lewis Research Center** *and D. J. Moracz and C. M. Austin of TRW, Inc. Further information may be found in NASA CR-174650 [N84-25711/NSP], "Fabrication Development for ODS-Superalloy, Air-Cooled Turbine Blades" [$13]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14179

Acoustic-Emission Weld-Penetration Monitor

Sounds could be used to control robotic welders.

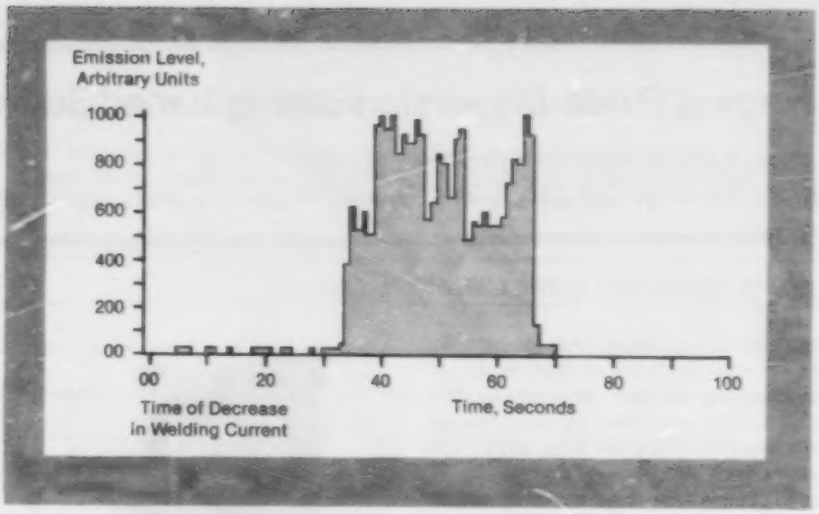
Marshall Space Flight Center, Alabama

Weld penetration can be monitored by the detection of high-frequency acoustic emissions produced by the advancing weld pool as it melts and solidifies in the workpiece. Such monitoring could be applied to the control of automated and robotic welders.

Experiments in tungsten/inert gas (TIG) welding have shown a clear correlation

between the depth of penetration and the level of acoustic emission (see figure). The coupling of an acoustic-emission monitor to the controller of an automatic or robotic welder could allow real-time adjustment of weld parameters (for example, arc current and travel speed), yielding optimal weld penetration. The measurement of the acoustic emissions could be made with such contact probes as piezoelectric transducers or, more effectively, with such noncontact probes as optical vibrometers or electromagnetic sensors that could travel with the welding head during the welding operation.

This work was done by Jonathan Maram and John Collins of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 64 on the TSP Request Card.*
MFS-29064



The **Acoustic Emission From a TIG Butt Weld** was measured with a 300-kHz resonant transducer. The rise in the emission level coincides with the cessation of weld penetration due to a sudden reduction in welding current.

Holder for Tinning Microcircuit Leads

Tool ensures that leads are tinned adequately but not excessively.

Lyndon B. Johnson Space Center, Houston, Texas

A heat-sinking tool holds microcircuits for lead tinning while protecting the circuits from the heat of the tinning solder. The application for which the tool was originally developed requires that the tinning not be closer than 0.02 in. (0.5 mm) from the package body or its glass seals.

As shown in Figure 1, the tool includes a small, two-part box that holds the microcircuit with the leads to be tinned protruding from the gap between the box halves. The box is fastened to the ends of a pair of tweezers, which squeeze them together around the microcircuit. The tweezers are the "normally closed" type.

An operator inserts a microcircuit in the box and allows the halves to clamp around the microcircuit. Soldering flux is then applied to the leads with an acid brush. The leads and the bottom of the tool are then rotated through the solder wave or pot (see Figure 2) with approximate timing as follows:

- One second to insert the leads into the solder,
- Two seconds to hold in the solder, and
- Two seconds to withdraw the leads from the solder.

The direction of rotation is important: The tool is moved so that the knees of the

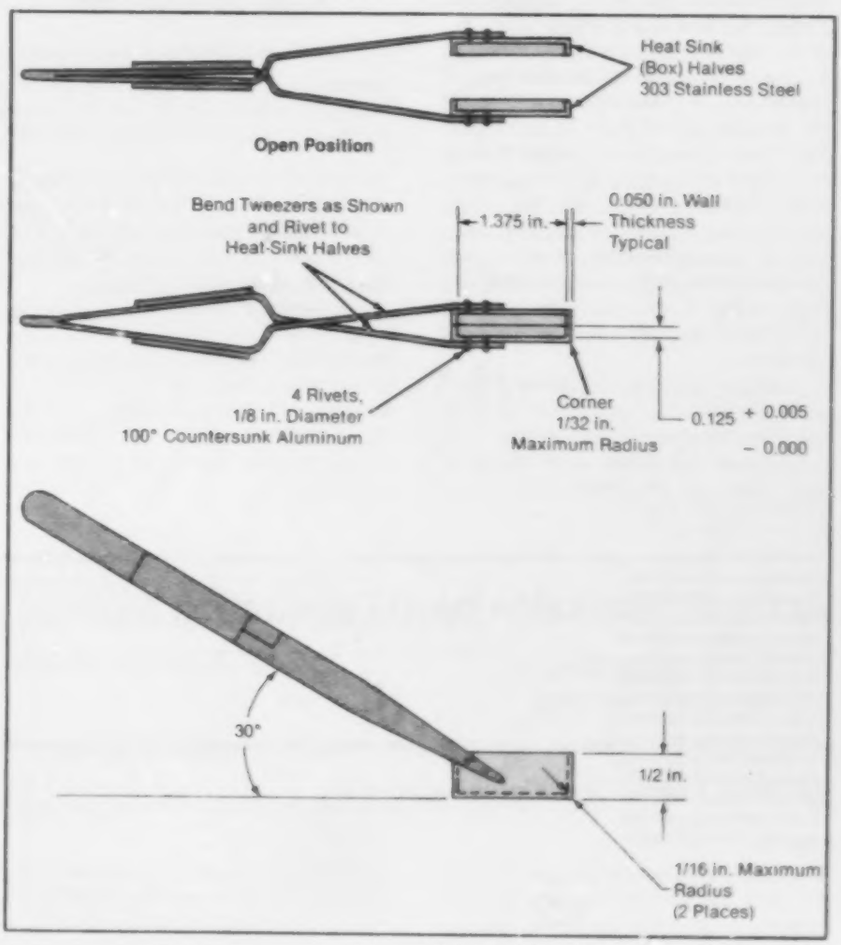

Heat Sink (Box) Halves 303 Stainless Steel
Open Position
Bend Tweezers as Shown and Rivet to Heat-Sink Halves
1.375 in.
0.050 in. Wall Thickness Typical
4 Rivets, 1/8 in. Diameter 100° Countersunk Aluminum
Corner 1/32 in. Maximum Radius
0.125 + 0.005 − 0.000
30°
1/2 in.
1/16 in. Maximum Radius (2 Places)

Figure 1. The **Heat-Sinking Tool** is made from a 6-in. (15.2-cm) pair of tweezers and a small hollow heat sink, each half of which is attached to a tweezer arm.

leads are ahead; otherwise, the leads will scoop up too much solder. After tinning, the tool and circuit are dipped in Freon TES (or equivalent) cleaning solvent to remove the flux and cool the parts. The circuit is then inverted in the tool and the process repeated to tin the leads on the opposite side.

This work was done by Gary G. Gilbert and George Dehnert Fielder of Sperry Rand Corp. for **Johnson Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 21]. Refer to MSC-20662.

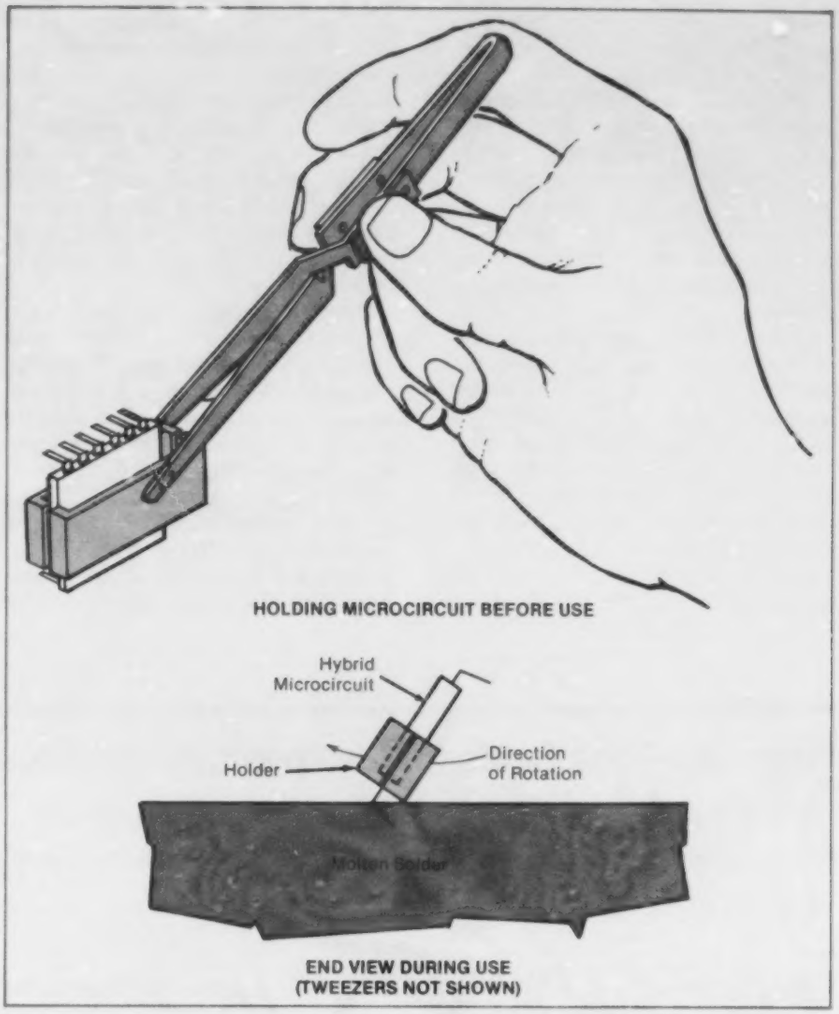


Figure 2. The **Microcircuit Holder** dips the leads in molten solder. The holder shields the microcircuit from the solder heat while the leads are immersed and absorbs heat conducted through the leads. It thus keeps the microcircuit relatively cool.

Improvements in Ionized Cluster-Beam Deposition

Lower temperatures would result in higher purity and fewer equipment problems.

NASA's Jet Propulsion Laboratory, Pasadena, California

Proposed improvements in the ionized cluster-beam deposition of semiconductor or other thin films would exploit the chemical reactivities and volatilities of selected reactants and resulting reaction products to enhance film properties.

The conventional cluster-beam technique typically requires high temperatures to vaporize the elements to be deposited (about 2,500 K for silicon). Such temperatures also cause vaporization of beam source materials of construction (for example, carbon), which become trapped in the beams and are incorporated into the thin films as contaminants. High temperatures also entail difficult problems of furnace design, heat shielding, measurements of vapor pressure and temperature, and the costs of the foregoing. The improved technique would eliminate these problems by using reactive gaseous compounds, which are volatile at much lower temperatures.

In cluster-beam deposition, clusters of atoms are formed by the adiabatic expansion of a vaporized material into a vacuum. With the proper choice of pressure and temperature upstream of the expansion nozzle and with proper nozzle design, the expanding vapor cools sufficiently to become supersaturated and form clusters of the material to be deposited. The clusters are ionized and accelerated in an electric field and then impacted on a substrate where the films are formed.

If gaseous compounds of thin-film materials are used instead of the pure elements, the temperatures required to achieve adequate vapor pressures are reduced. Gases that lend themselves well to this improved technique include phosphine, arsine, germane, silane, and the metal halides. These compounds have vapor pressures sufficiently high to allow cluster formation at temperatures of only 200 to 300 K.

The source for a volatile-gas cluster beam is essentially a stagnation chamber with a nozzle and with flow and pressure controls. Temperature control is not as critical as in the conventional technique because stagnation pressure is established by mass flow instead of by vapor-pressure equilibrium. To the degree to

which temperature control might be required, it is much easier at the lower temperatures.

Impurity levels in the deposited films would depend on the purities of the reactant gases, background vacuum constituents, and the retention of the volatilizing elements (e.g., hydrogen from silane remaining in a silicon film). Several approaches have been proposed to control the concentration of the volatilizing species.

In one version, the reactant compound(s) would be exposed to an electrical discharge or ultraviolet radiation just upstream of the nozzle to generate a polymolecular gas before the clusters are formed. For example, some of the bonds of a hydride would be broken to form a distribution of molecular fragments having different hydrogen contents. Due to the higher supersaturation of the molecules lower in hydrogen, clusters rich in the elements to be deposited would be formed. The nonsupersaturated constituents, including molecular hydrogen, would aid the clustering process by carrying off part of the latent heat of condensation. The deposit would be rich in the volatilizing element, and this version would therefore be useful when the volatilizing element would be beneficial; for example, when hydrogen is needed to cap dangling bonds in silicon.

Another approach would use reactive gas mixtures that are stable under clustering conditions. After being ionized and accelerated to several electronvolts per molecule, the gas clusters have sufficient energy to initiate the mixture reaction upon collision with the substrate. For example, silane and chlorosilane would react in this way to deposit silicon and evolve volatile hydrogen chloride gas. In a third approach, a pure hydride (e.g., silane) would simply be accelerated to such an energy that impact alone would cause the desired element to be deposited and the volatilizing element (hydrogen) to be set free.

The improved cluster-beam technique might be useful for the deposition of refractory metals. An additional elaboration of the basic technique might be the merging of two or more beams to deposit films of more than one element. Another variation might be to put a dopant gas into the vacuum chamber at a low background pressure so that some of the dopant becomes entrained in the beam and deposits in the film.

This work was done by Dennis J. Fitzgerald, Leslie E. Compton, and Eugene V. Pawlik of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 68 on the TSP Request Card.*
NPO-16518

Hermetic Edge Seals for Photovoltaic Modules

Corrosive atmospheric agents are excluded to prolong cell life.

NASA's Jet Propulsion Laboratory, Pasadena, California

A combination of two sealing techniques makes it possible to protect solar cells from water vapor, oxygen, and other corrosive atmospheric constituents. Using a three-step process, a glass-to-metal hermetic seal is formed around the edge of a solar-cell module. The elastomer seals that were used previously are not as effective because they are permeable to water vapor and atmospheric gases.

First, electrostatic bonding is used to attach an aluminum-foil gasket to the perimeter of the glass cover sheet of the module. Electrostatic bonding is a field-assisted process in which free oxygen ions in the glass chemically bond to the foil, forming a thin aluminum oxide layer at the interface. The process requires a temperature of about 350° C.

The module is then encapsulated behind the glass in a standard laminating or casting process. Since the gasket is already in place, it is not necessary to expose the module to damage by the high bonding temperature.

A back cover of aluminum foil is bonded to the aluminum-foil gasket by ultrasonic welding. This step completes the hermetic seal without heating the module excessively

This work was done by Michael J. Nowlan of Spire Corp. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 62 on the TSP Request Card.*
NPO-16427

Television Monitoring System for Welding

The welding process in visually inaccessible spots is viewed and recorded.

Marshall Space Flight Center, Alabama

A television system enables the monitoring of welding in visually inaccessible locations. The system can assist welding operations and provide a video record, which can be used for weld analysis and for welder training.

The optical image of the arc and weld puddle is transmitted to a 3- by 3- by 2-in. (7.6- by 7.6- by 5.1-cm) charge-injection imaging-device camera via a bundle of optical fibers, a lens, and a filter. The flexible fiber-optic cable can be mounted directly on the welding head. A motorized filter wheel enables the remote selection of the appropriate filter (for example, to reduce the glare from the arc, thereby producing a clearer image of the welding process). The system includes a compatible television monitor.

This system allows visual access to many areas not accessible to conven-

tional optical equipment: For example, it can be used in a titanium weld booth and (with an added light source) to view the back side of a weld to see the penetration during welding.

This work was done by Karen Vallow and Steve Gordon of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 103 on the TSP Request Card.*
MFS-29104

Wrinkle-Free Hydroforming of Wire Mesh

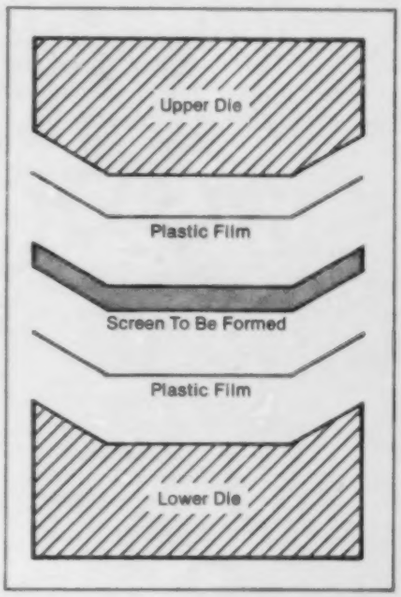
Plastic films lubricate the workpiece so that it deforms smoothly.

Marshall Space Flight Center, Alabama

A new method of hydroforming fine-wire-mesh heat-shield screens eliminates wrinkles and marks. The new method thus prevents a screen from being damaged and its pores from becoming blocked.

In the new method, thin sheets of a plastic such as polytetrafluoroethylene are molded in the same shape as that of the screen to be formed, and are inserted between the screen material and the upper and lower dies before hydroforming (see figure). The sheets reduce friction and allow the screen to slide more freely between the dies during hydroforming. The screen thus accommodates readily to the shapes of the dies without folding or excessive stretching.

This work was done by John Fadness of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29111



Thin Layers of Plastic below the top die and above the bottom die ensure that a wire screen slides as it is shaped by hydroforming. The plastic layers are 0.0043 in. (0.11 m) thick. They are preformed to the contours of the dies and the final workpiece.

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140 Derivatives of the Arithmetic-Geometric Mean

Derivatives of the Arithmetic-Geometric Mean

Electrostatic fields in clouds are estimated more precisely.

Marshall Space Flight Center, Alabama

A mathematical technique enables the computer evaluation of derivatives of the arithmetic-geometric mean. Developed for theoretical studies of lightning requiring estimates of electric fields in clouds, the technique is expected to reduce computation time and improve accuracy.

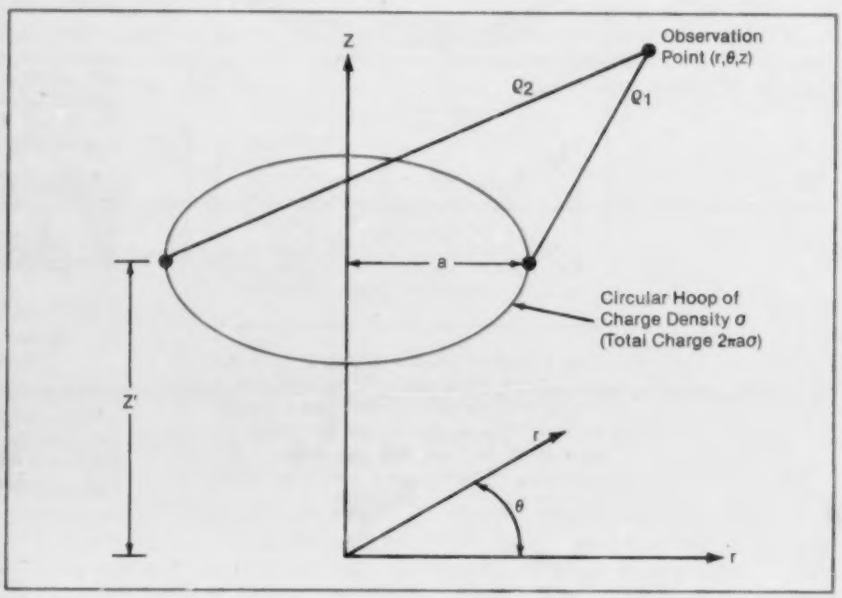
For estimating purposes, a cloud is treated as having a cylindrical shape, and the electrical charge in the cloud is modeled as an array of charged circular hoops. The electrostatic potential of this charge distribution observed at a specified location is calculated as the sum of the potentials at that location arising from the individual hoops.

The arithmetic-geometric mean is a function that appears in the denominator of the expression for the hoop potential. It incorporates the effects of the hoop radius and the distance and direction from the center of the hoop to the observation point (see figure). The arithmetic-geometric mean represents, in effect, a fictitious distance, g: The potential at the observation point equals the potential that would be observed at a distance g from a point charge of magnitude equal to the charge on the hoop.

Since the electric field is just the negative gradient of the potential, the calculation of the electric field at a point requires the calculation of derivatives of the arithmetic-geometric means of the hoops. Using the geometry of the figure, the derivatives needed to calculate the electric field are $\partial g/\partial r$ and $\partial g/\partial z$.

The procedure for numerically evaluating these derivatives by computer is analogous to that for evaluating the arithmetic-geometric mean itself. It involves successive approximations based on derivatives of the arithmetic mean and of the geometric mean obtained from the preceding approximation. As in the case of the arithmetic-geometric mean itself, the procedure for the derivatives converges rapidly.

This work was done by Frank B. Taton of Engineering Analysis, Inc., for **Marshall Space Flight Center.** *For further information, Circle 83 on the TSP Request Card.*
MFS-26018



The **Arithmetic-Geometric Mean** is a fictitious radius with magnitude between ϱ_1 and ϱ_2. It expresses the spatial dependence of the electrostatic potential arising from the hoop of charge.

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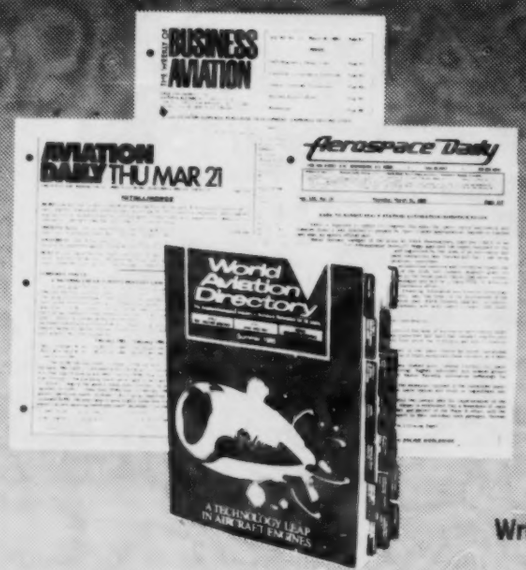

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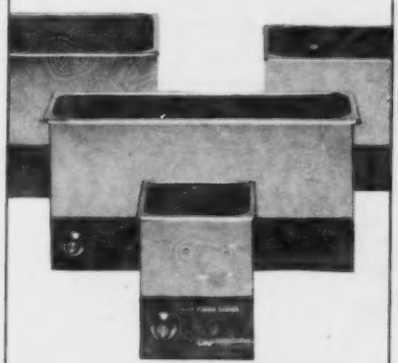

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Letters

The "Letters" column is designed to encourage a wide exchange of ideas among *NASA Tech Briefs* readers. To contribute a request for information or to respond to such a request, use the feedback cards in this issue, or write or call: Manager/Technology Transfer Division, P.O. Box 8757, Baltimore/Washington International Airport, MD 21240; (301) 859-5300. While we can print only a small number of letters, we will endeavor to select those that are of varied and wide interest.

GETTING SPECIFIC

The computer maintenance technology program has been in existence here at TSTI for only one year. We have received a few of the Tech Briefs *today, and after reading them plan to integrate them into our program as soon as possible. They are well written.*

We are training people to component-level in computer and peripheral repair. Your tech briefs are well ahead of any textbooks available and allow us to train people closer to state of the art.

Robert J.K. Larsen
Instructor/Resource Officer
Texas State Technical Institute
Waco, TX

I have long been interested in solar power and, through the information you provided, I have built a solar power system at home. This project led me to the design of an automatic tracking system for plate collectors, which has been operative for three years and is working fine.

Glenn E. Eiden
Sr. Laboratory Technician
Magnavox Electronic Co.
Fort Wayne, IN

We have investigated means of reducing aerodynamic drag on tractor-trailer trucking operations. This was started by an article in NASA Tech Briefs *on modifying a tractor-trailer configuration. Your article was based on theory and was not practical for our purposes, i.e., no provision for bumpers or window wipers on tractors. However, we did modify our truck fleet to improve fuel efficiency.*

Henry Dankenbring
Mechanical Engineer
Pepperidge Farm, Incorporated
Norwalk, CT

Our lab supports research and development of propellants and components for ICBMs. In that role, new test and measurement techniques are being developed. One of the articles stimulated our interest in using ultrasonics as an epoxy cure monitoring method. The success has led to many other uses. Reading your briefs is like brainstorming with experts in every discipline—a great help.

James R. Dyal
Process Engineer
Aerojet Propulsion Co.
Sacramento, CA

The Summer 1985 issue has two very useful articles on arc lamps. I was reading about commercial assemblies, but now plan to build my own from your diagrams! This will save me a good deal of money.

John Hoebing
Physicist
Spectradyne
Chicago, IL

Having a wind charger system and battery bank requiring distilled water, I have scaled down a solar distiller shown in your pages to produce a system to meet my needs. Prior to building the small version, I was constantly buying bottled water. Many of your flat plate collector ideas have been put aside for later experimentation.

Brad Evans
Senior Industrial Engineer
Fairchild Aviation
San Antonio, TX

A tech report originally published in German was translated and made public by NASA's TU program. It is of utmost practical importance to what I am doing at present. The paper is on debinderizing reactions in ceramics at various temperatures. It helped us to understand the organic reactions with ceramics better, to set up firing schedules more scientifically, and to save substantially on fuel. I personally applaud NASA's TU endeavors in such instances of technology transfer and utilization.

Sanjoy K. Das
Ceramic Engineer
R & W Products, Inc.
Auburn, CA

I will use Tech Briefs *to help me find new materials (ex: thermal setting plastics, graphite composite plastic compounds, etc.) to make new and better braces for orthopedics and sports industries. I'm also interested in cryo-technology as related to the medical industry—specifically physical therapy management of sports injuries.*

Thomas E. Detty
Director of R & D
Pro Orthopedic Devices, Inc.
Tucson, AZ

NASA Tech Briefs has brought my company into contact with federal research labs, thus helping dissemination of technology a small company cannot afford.

Peter H. Karatassos, Ph.D.
Optimum Technologies, Inc.
Big Flats, NY

QUID PRO QUO

*The advertisement (*NTB, *Fall '85, p.167) showing the American businessman shooting himself in the foot with a smile (not a grimace) is indicative of American business acumen. Your "briefs" appeal greatly to the entrepreneur. Is there any organization that takes these inventions to product utilization?*

Orlando Holway IV
Marketing Manager
Omnimedical
Antioch, IL

We are a fairly new company, organized to commercialize existing and emerging technology by developing new products which can be used by industry, government, academia and the public in general. We are using back issues of Tech Briefs *and will use* Tech Briefs *to identify those developments which can be integrated into our data base for evaluation and application to our commercial ventures.*

J.R. Maxfield
Chairman of the Board
Corp. for Commercial Space Industries
Houston, TX

Many times I wonder if other manufacturers are developing and selling equipment based on NASA research. For example, the acoustic flame efficiency meter might already be nearly available, and I would not have to go through further experiment and prototype. Could you flag such a situation in "Briefs"?

D. Hammerton
Principal Engineer
Polaroid Corp.
Norwood, MA

Many of the inventions reported in *NASA Tech Briefs* are patented or are under consideration for a patent at the time they are published. The current patent status is described at the end of the article; otherwise, there is no statement about patents. If you want to know more about the patent program or are interested in licensing a particular invention, contact the Patent Counsel at the NASA Field Center that sponsored the research (see page 21). Be sure to refer to the NASA reference number at the end of the Tech Brief.

In addition to inventions described in *NASA Tech Briefs*, "NASA Patent Abstract Bibliography" (PAB), containing abstracts of all NASA inventions, can be purchased from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. The PAB is updated semiannually.

AS YOU LIKE IT

Found article on Ames very interesting, since it is just down the street from our company. Would appreciate article about SARSAT program—this is among my latest interests.

Dr. M. Mladejovsky
Manager, CAD
Performance Semiconductor
Sunnyvale, CA

Could Tech Briefs *dedicate some space to the topic: "What NASA Would Like to Do But Isn't Doing"?*

Benjamin J. Harris
Senior Engineer
Martin Marietta
Denver, CO

It would be most helpful to include a dozen or so reviews of GAS can experiments and related instrumentation, and compare hardware and software for bio, pharmaceutical and silicon processing with other new tech brief offerings. This would be most productive in getting more users on shuttle flights quickly with good results.

David Hessler
Engineer
Burroughs
Paoli, PA

We read with interest all your articles on hydrogen storage and handling. I would like to see articles on small business/NASA working together.

Gregory J. Egan
Marketing Manager
Hydrogen Consultants
Denver, CO

Editorial Note: *NASA Tech Briefs'* editors welcome your comments and suggestions regarding our feature articles. We will endeavor to address your interests as we expand the editorial focus of the magazine, but first we need to know what your interests are. Please send your comments and suggestions directly to the Editor, NASA Tech Briefs, 41 East 42nd St., Suite 921, New York, NY 10017.

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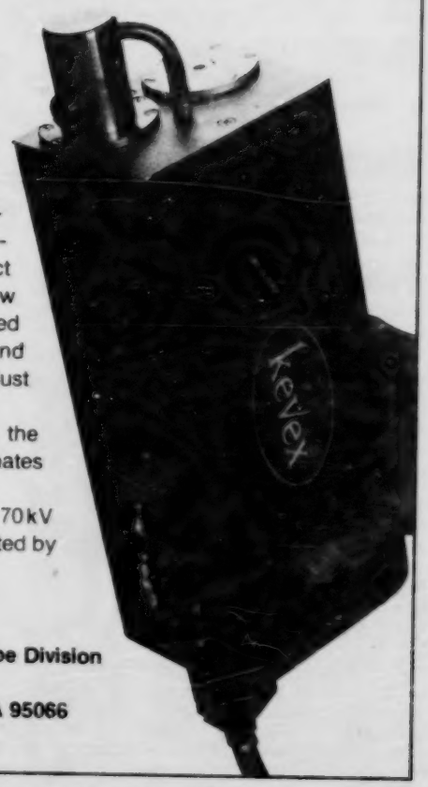

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Further Information on Innovations—Although some new technology announcements are complete in themselves, most are backed up by Technical Support Packages (TSP's). TSP's are available without charge and may be ordered by simply completing a TSP Request Card, found at the back of this volume. Further information on some innovations is available for a nominal fee from other sources, as indicated. In addition, Technology Utilization Officers at NASA Field Centers will often be able to lend necessary guidance and assistance.

Patent Licenses—Patents have been issued to NASA on some of the inventions described, and patent applications have been submitted on others. Each announcement indicates patent status and availability of patent licenses if applicable.

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Through the technology transfer process, many of the systems, methods and products pioneered by NASA are re-applied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.

"Moving with air, everywhere" would be a fitting slogan for Hovair Systems, Inc. of Ventura, California. Its air film flotation systems provide practically frictionless, omnidirectional lift and transport for all manner of heavy and unwieldy loads. From moving prefabricated home modules between factory assembly stations to rearranging audience seating configurations in television studios and stadiums, Hovair's air film systems facilitate a variety of processes, ranging from manufacturing to entertainment.

Hovair's systems are an outgrowth of a technology originally developed by General Motors during the mid-1960s. Under contract to NASA's Marshall Space Flight Center, General Motors adapted its previously invented air flotation device for a new, large-scale application—moving the components of the gargantuan Saturn V rocket during construction and assembly.

Following the success of this first large-scale application, a group of General Motors engineers who had developed the air bearing technology obtained a license for it, and formed a company to refine and market air bearing systems to private industry. A diverse line of air film transporters, turntables and air cushions for frictionless movement of moderate to heavy loads was introduced in the late 1960s.

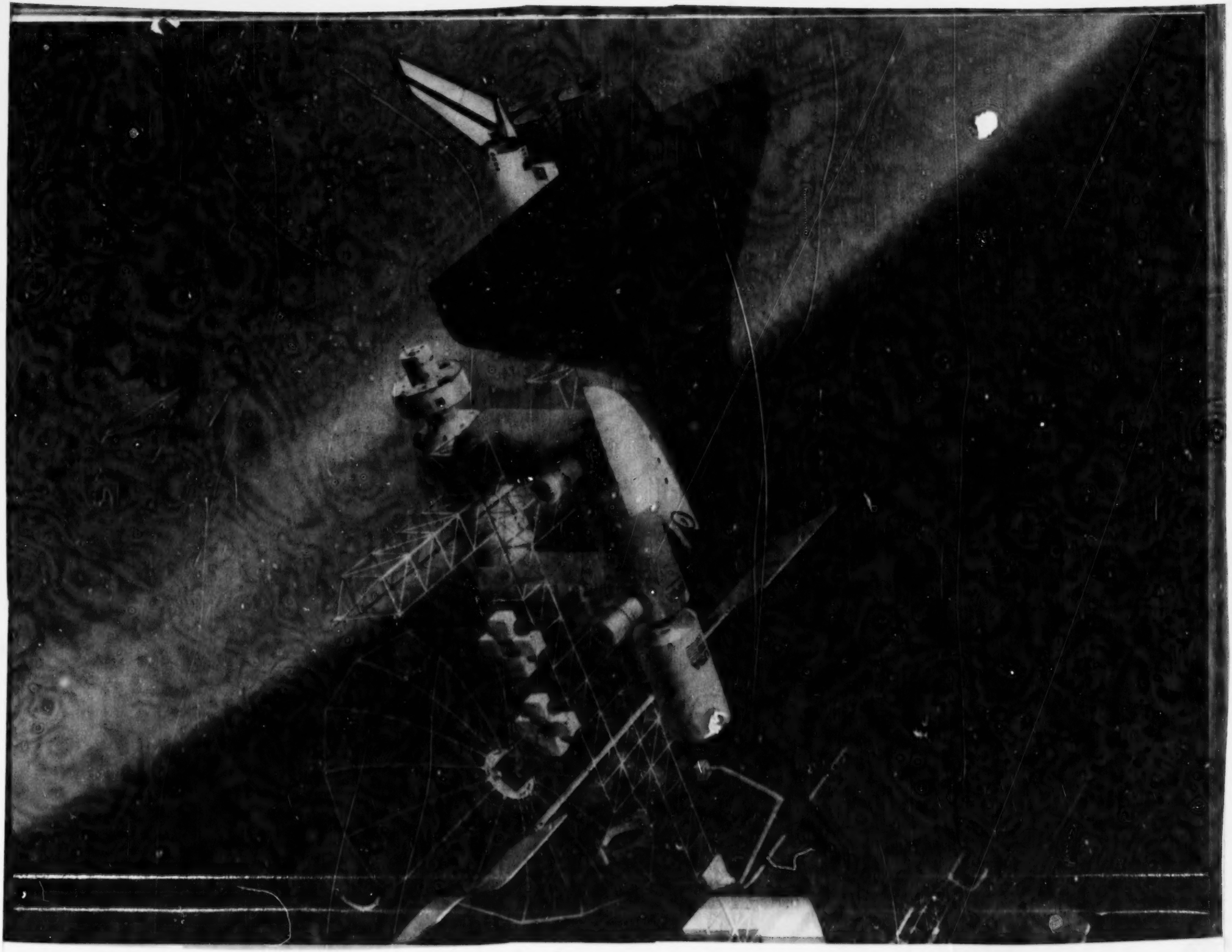
The basic building block of the air bearing system is a standard transporter unit. It incorporates air bearings into a steel frame, combining a mounting and positioning surface for the air bearings with a payload platform and a container for associated pneumatic components. The size of the transporter varies according to its application, and the number, size and configuration of the air bearings are also established in proportion to the application. Fundamentally, however, the system's elements are the same in every application.

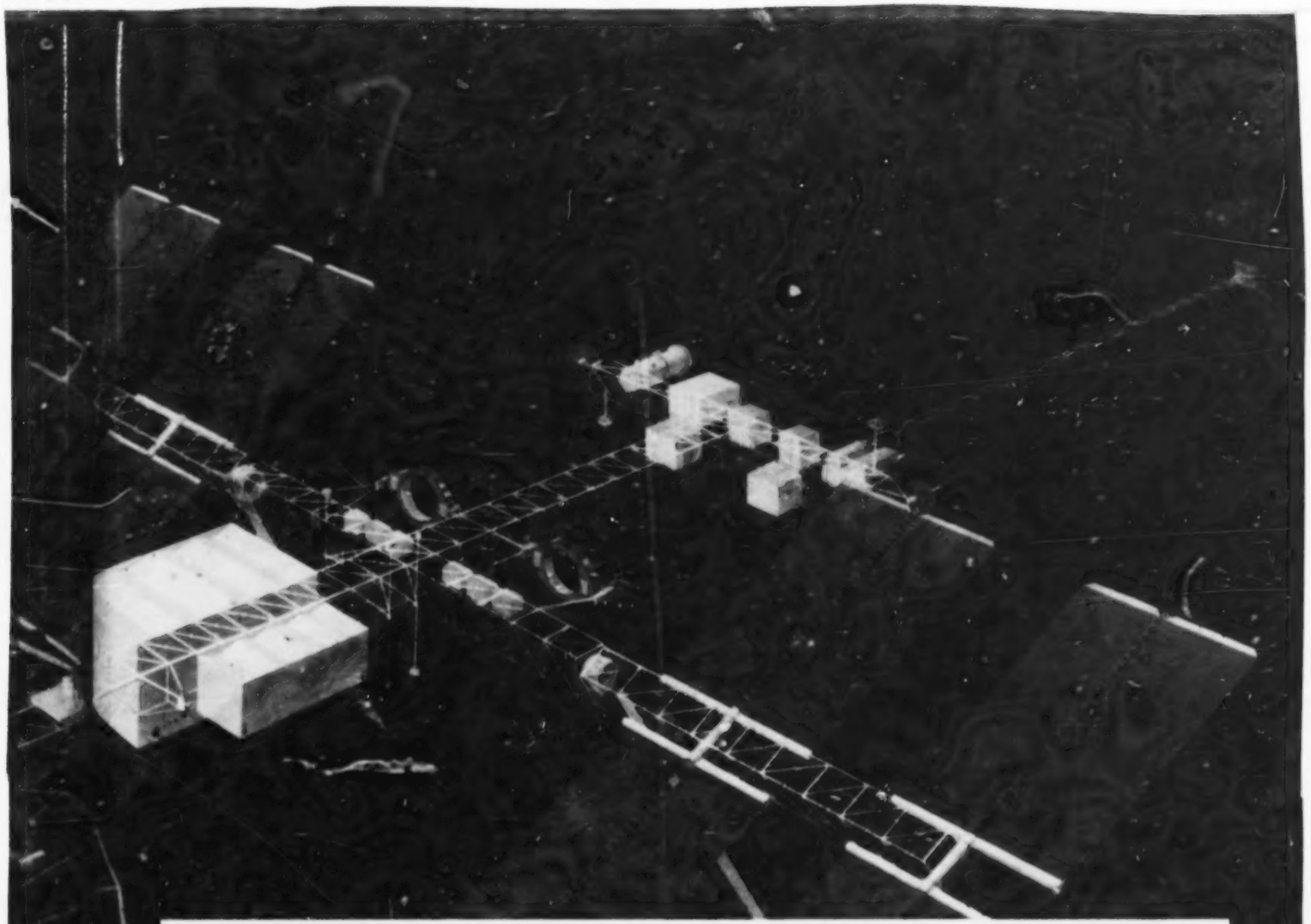
The air film load transporter utilizes compressed air from a pre-existing factory supply, making individual hose connections for each transporter unit unnecessary. As air pressure is introduced to the system, the bearings inflate and expand in much the same manner as traditional rigid air cylinders. However, as air pressure increases, it reaches a value at which the compliant diaphragm is fully extended and the total upward lift balances the downward force of the applied load. At this point, a separation occurs between the operating surface of the transporter and the lower surface of the compliant air bearings, generating an air escape path and creating a dynamic lubricating system. The resultant thin cushion of air eliminates frictional contact, and allows movement of the lifted load at a one-to-one thousand force/weight ratio.

Hovair currently manufactures 100 standard air film systems, in addition to customized designs, such as one supplied to Hughes for simulating the unfolding of satellite solar arrays in a frictionless environment. In this particular application, the bearings lift a load weighing only 60 pounds, but for Allis-Chalmers, Hovair supplied a system for lifting and transporting 60-ton tractors along the production line. The addition of accessory elements for powered movement, automatic control and guidance further extend the range of Hovair's custom and standard systems alike.

Air film movement systems continue to gain acceptance across a broad spectrum of industry, and are particularly popular in heavy equipment manufacturing. This can be attributed to the advantages over traditional transport which air film systems offer. Applicable in a variety of sizes and configurations, they are highly adaptable to designer requirements. Further, they require little if any foundation work and can be moved in the event of relocation or reconfiguration. Finally, they're energy efficient and low cost, both initially and over time, which makes them especially appealing to those who want to float a load without having to float a loan. □

Although widely applied in other industries, air film systems remain active in their original large-scale application. Above, air film transporters position 180-ton segments of space shuttle solid rocket boosters for test firing in Utah. Below, a crane lowers a transporter unit containing 12 compliant air bearings into position at the Utah site.





Zero defects at zero gravity.

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Honeywell combines advanced technology with reliable performance to ensure America's space program will succeed well into the 21st century—and beyond.

Honeywell Reliability

Together, we can find the answers.

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A BUILDING SITE LIKE NO PLACE ON EARTH.

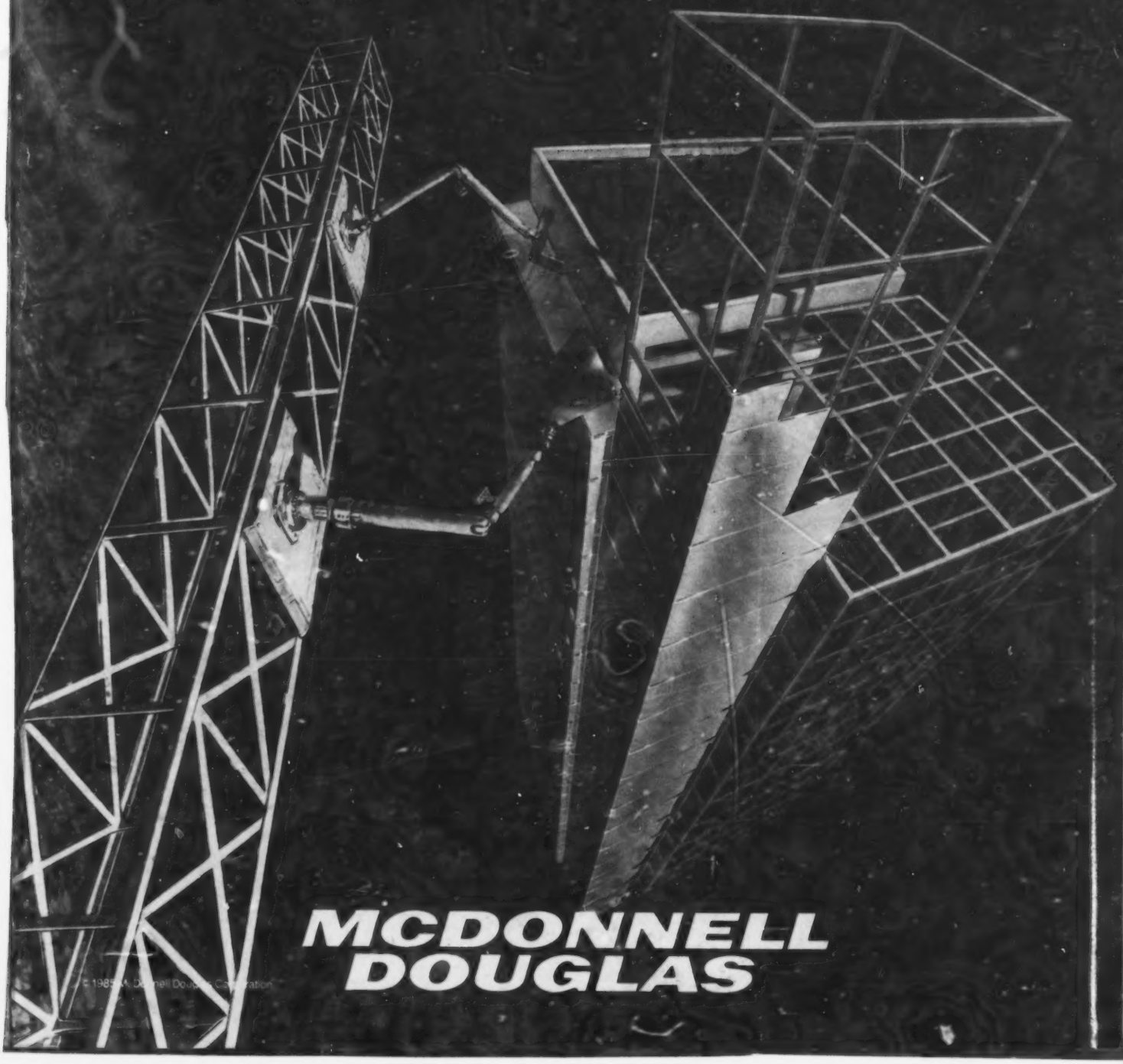
Some structures needed in space are just too big to launch in one piece. Too large and too fragile even to stand alone on Earth, intricate sections can be brought up on successive shuttle flights, plucked from the orbiter by station robot arms, assembled into massive structures by the space station crew, and released to their own orbits. The miracle of microgravity will make light work of such space construction.

One example is the 20-meter diameter Large Deployable Reflector infrared telescope NASA is planning for the mid-1990s. Consisting of some 100 pieces—large mirrors and supporting structures—when assembled and deployed, the device will permit a variety of deep space investigations.

Without the manned space station, structures of this size would not be possible.

We think that's a very good reason to build a building site like no place on Earth.

With Eastman Kodak and NASA, McDonnell Douglas is planning the precision techniques needed for construction in space. We are teamed with Honeywell, IBM, Lockheed and RCA for major definition and design work on the station.



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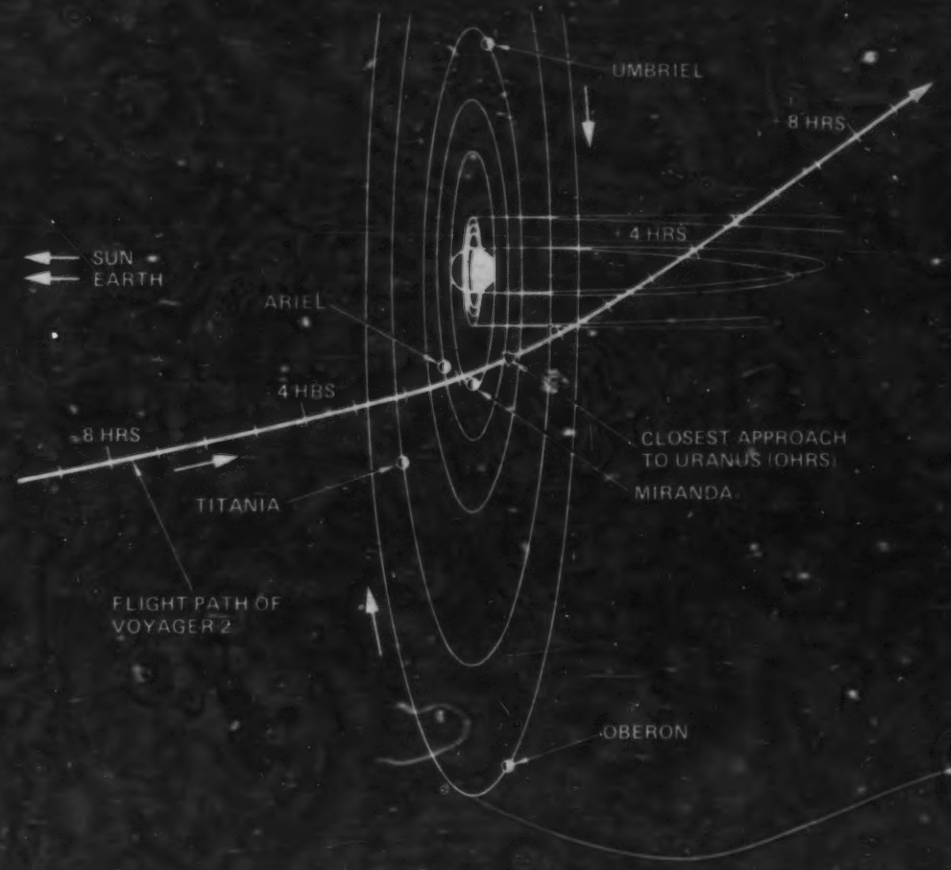
NASA Tech Briefs

National Aeronautics and Space Administration

March/April 1986
Volume 10, Number 2

Pushing Back the Frontier: Voyager 2's Flight Past Uranus



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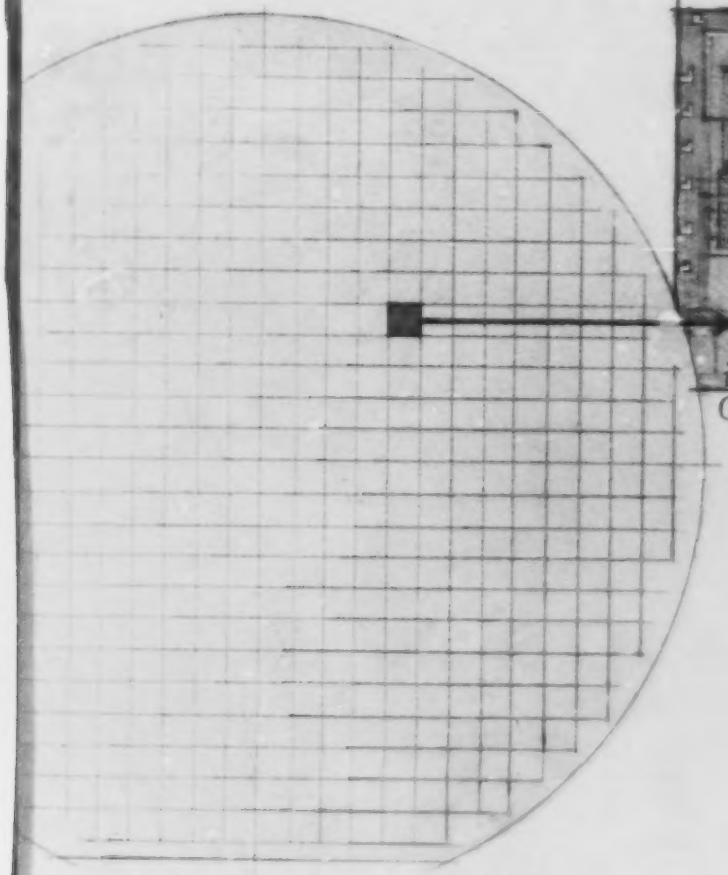
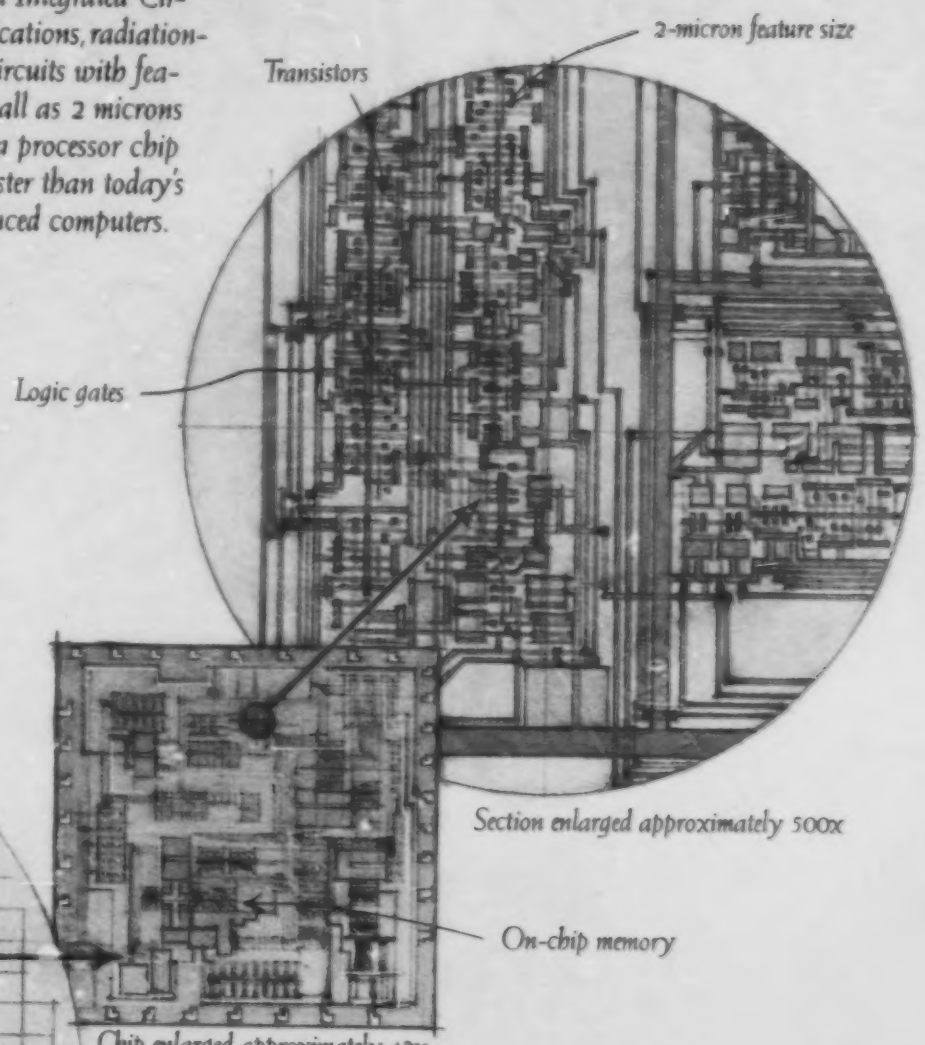


5" dia. wafer containing 430 VLSI chips



Section enlarged approximately 500x

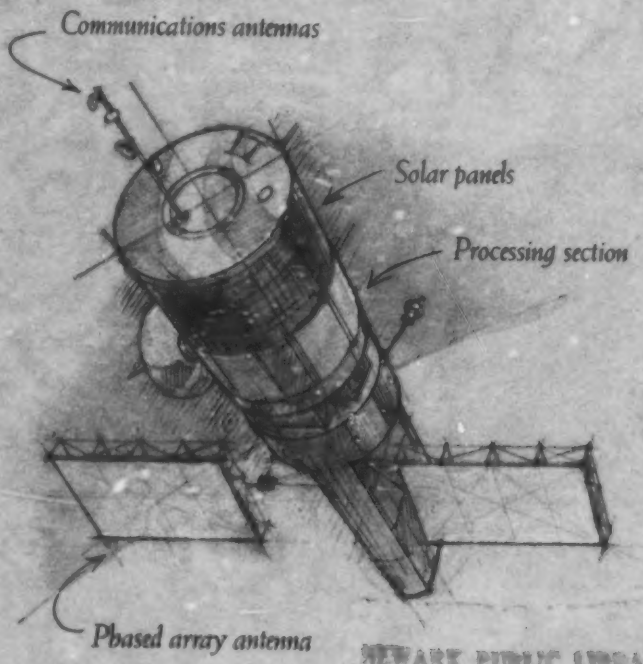
Chip enlarged approximately 12x

Greater density for higher speed.

Over 100,000 transistors are routinely being placed on VLSI chips. Tight packing shortens the signal path, which increases processing speed and reduces power needs.

Defense satellites with brains.

To identify, track and inventory thousands of objects in space, satellites will need radiation-hardened circuits capable of billions of operations per second. They'll be vital for such functions as battle management, communications, damage assessment, aiming and pointing.



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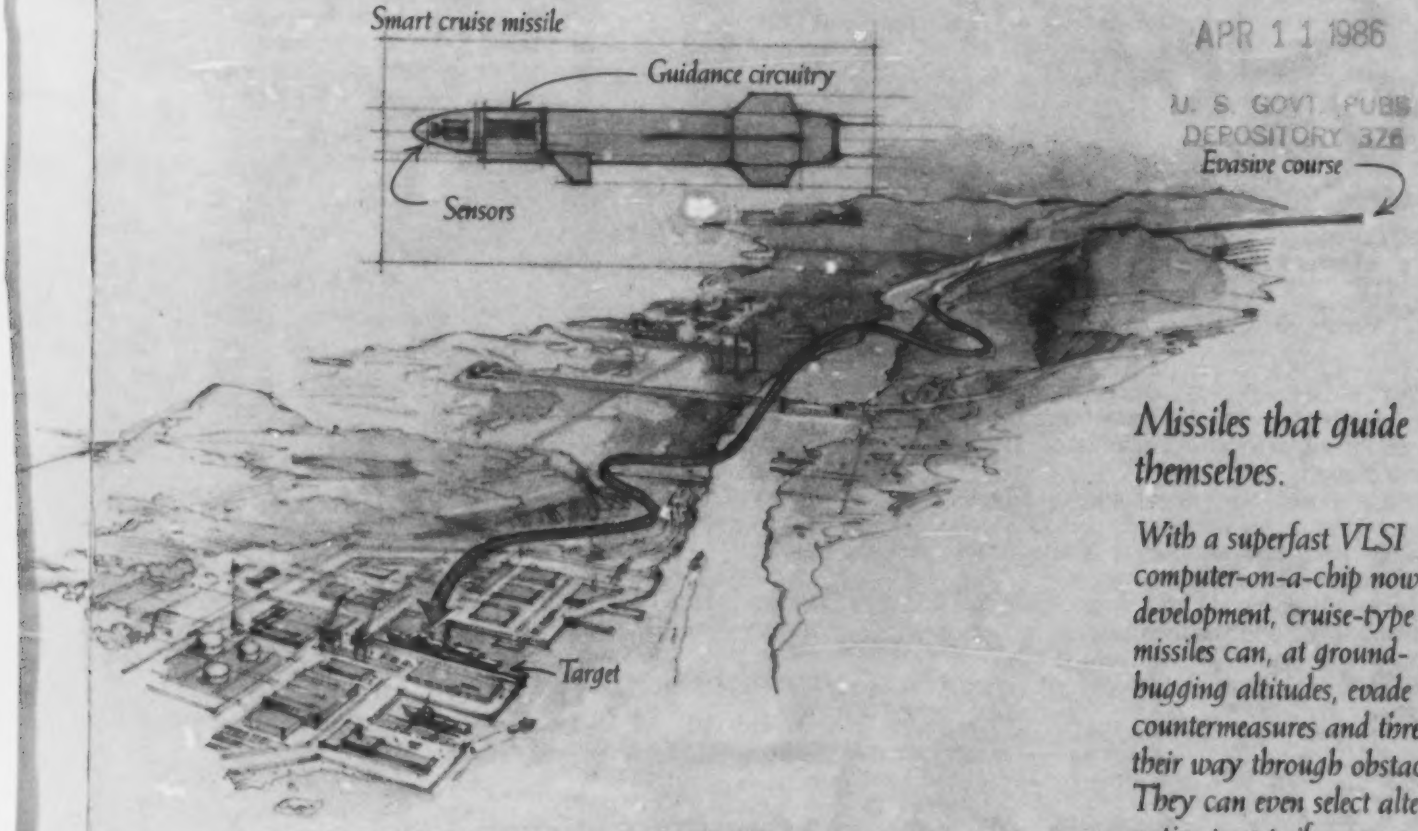

Missiles that guide themselves.

With a superfast VLSI computer-on-a-chip now in development, cruise-type missiles can, at ground-hugging altitudes, evade countermeasures and thread their way through obstacles. They can even select alternative targets if necessary.

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Space Operations Manager

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MARCH/APRIL 1986
Volume 10 Number 2

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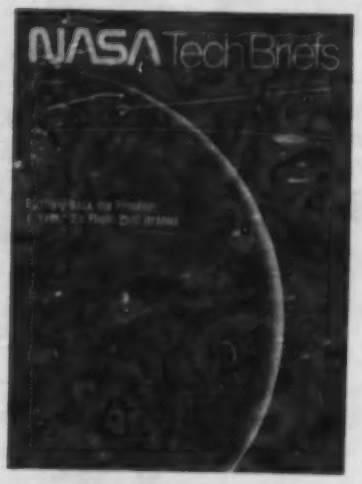
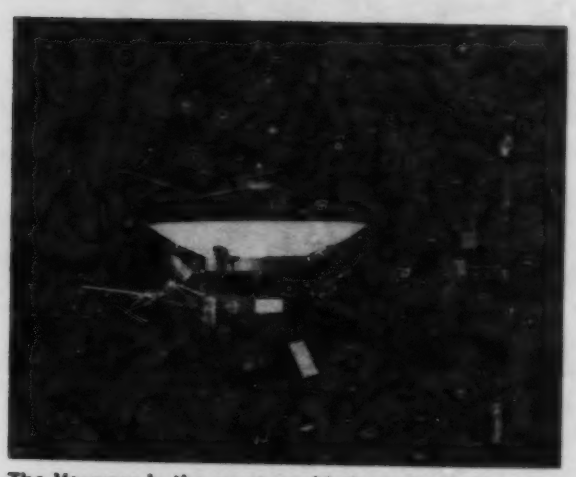


ON THE FRONT COVER:
This wide-angle image of Uranus was recorded by Voyager 2 on January 25, 1986, as the spacecraft left the planet behind and set forth on its journey to Neptune



The Voyager is the most sophisticated robotic spacecraft ever to have flown. It carries scientific instruments and two cameras, and is governed by three sets of twin computers. The Voyager project is managed by NASA's Jet Propulsions Laboratory...page 14.

NASA research on self-contained ecosystems led to the development of the EcoSphere®, an ecologically balanced system capable of sustaining plant and animal life...page 157.

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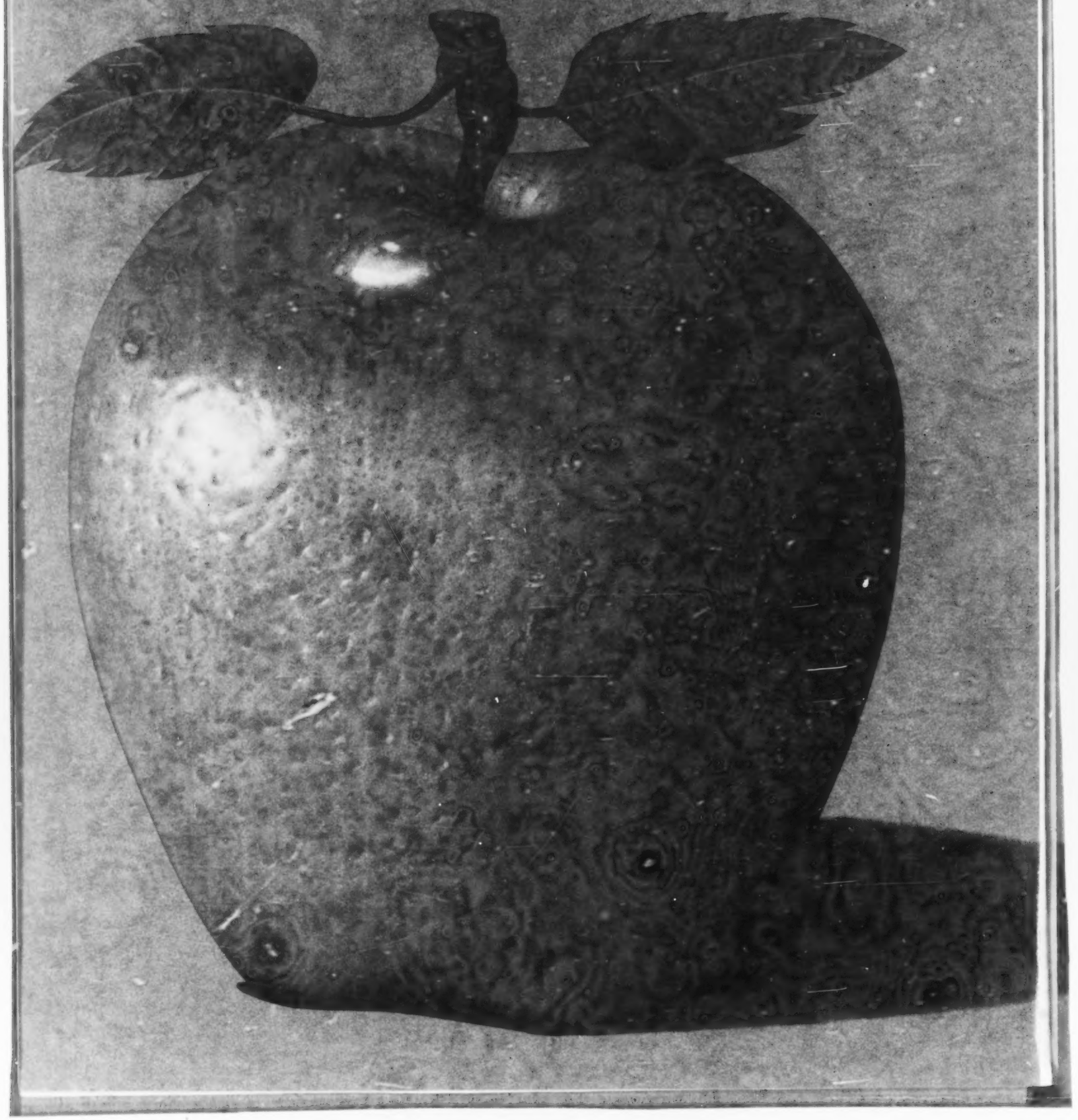

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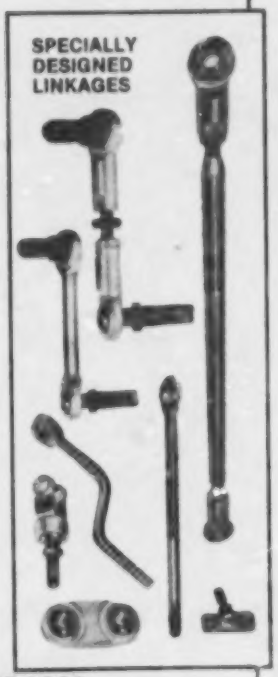

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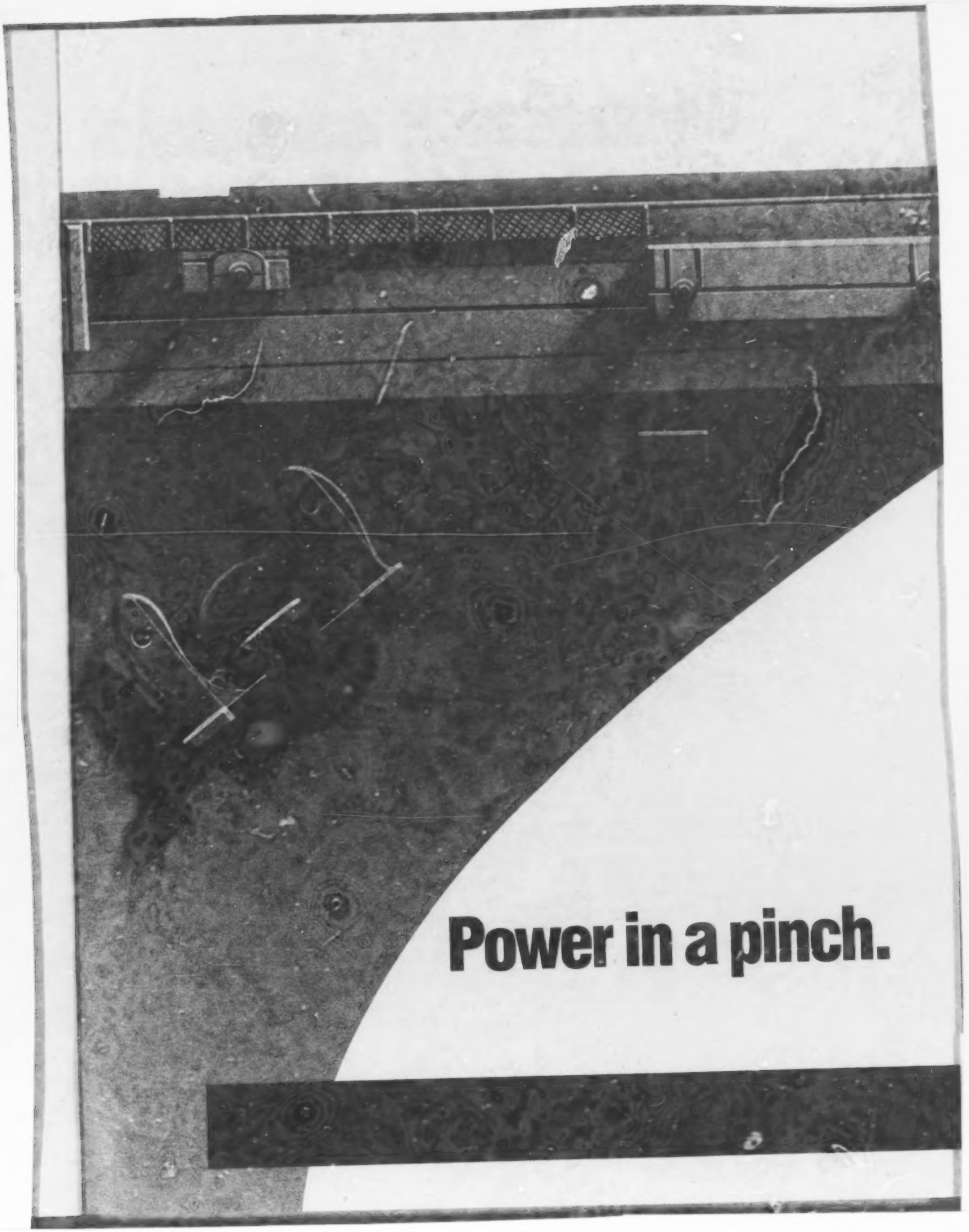
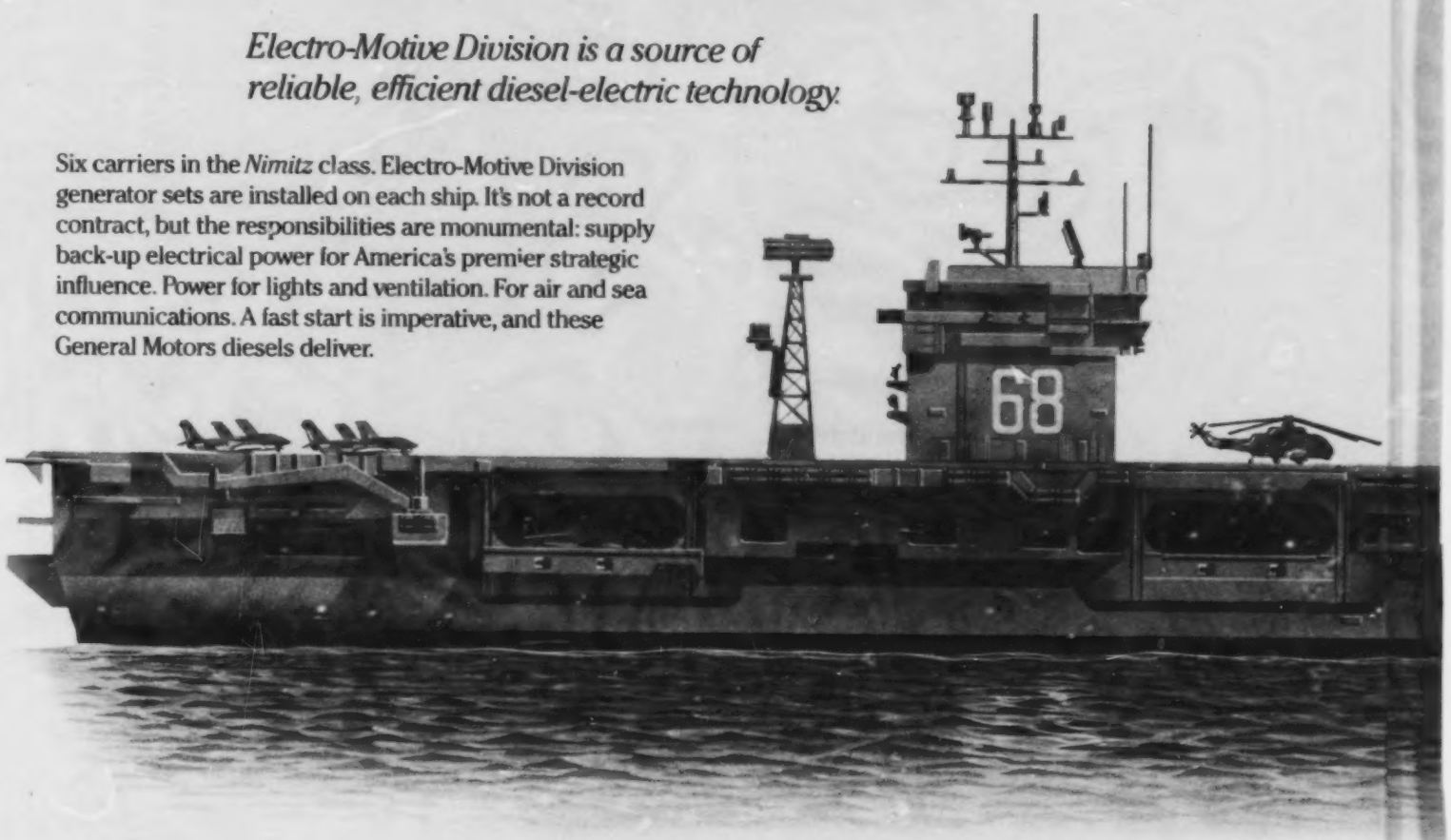

Power in a pinch.

When the nuclear reactor needs support, General

Electro-Motive Division is a source of reliable, efficient diesel-electric technology.

Six carriers in the *Nimitz* class. Electro-Motive Division generator sets are installed on each ship. It's not a record contract, but the responsibilities are monumental: supply back-up electrical power for America's premier strategic influence. Power for lights and ventilation. For air and sea communications. A fast start is imperative, and these General Motors diesels deliver.



Simplicity breeds reliability. Every GM generator set is based on the uncomplicated power of a GM two-stroke cycle diesel engine. Units configured with 8, 12, 16, or 20 cylinders deliver power outputs from 1000 to 4000 HP. The straightforward design results in a generator that starts fast, makes maintenance easy, and lasts. The service life of an EMD engine is typically 20 years or more.

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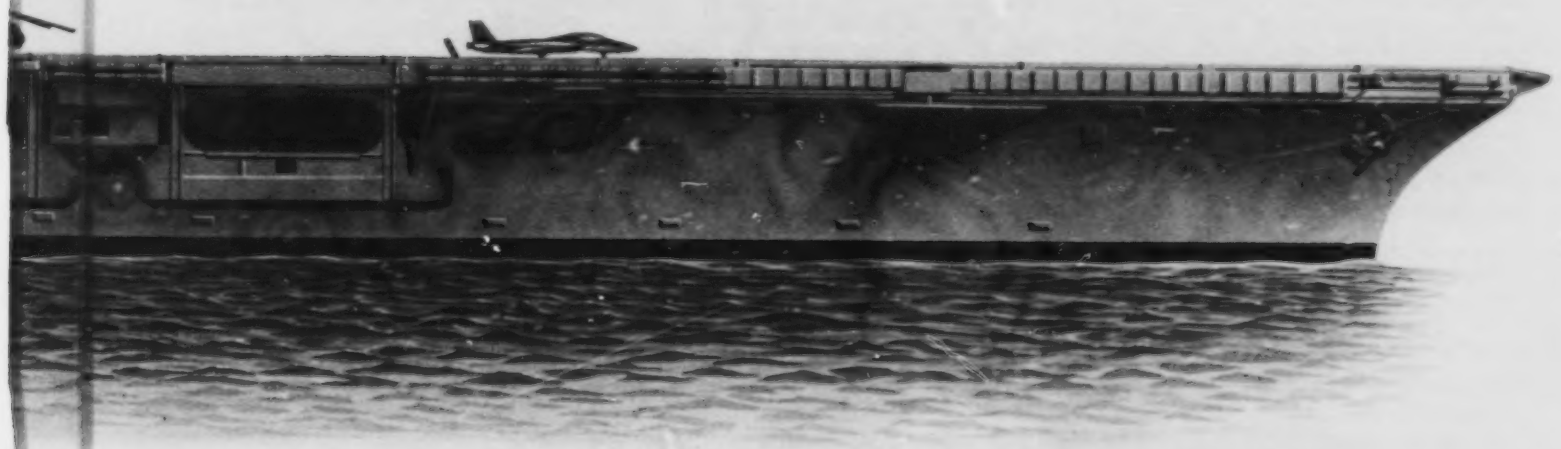
r in a Nimitz-class carrier
l Motors diesels react.

The Electro-Motive Division of General Motors has a long history of turning its production capacity and innovative abilities toward the defense community. During World War II, many U. S. Navy fleet submarines were driven by GM engines. We also delivered thousands of diesel engines for LSTs in the rapid build-up of our nation's landing forces.

For the Korean conflict, EMD designed and built a diesel-electric locomotive that was capable of operating on any gauge track. More recently, we developed portable generator sets for rugged duty in Southeast Asia. That they are still in the Army's inventory is a tribute to their flexibility and durability.

Electro-Motive diesel locomotives are controlled by a microprocessor. And the generator sets on the *Nimitz*-class are tested to "Hi-shock" standards for combat sea duty.



General Motors is always proud to qualify a commercial product for military service. This aggressive policy, combined with our defense experience, is the reason we enjoy such broad acceptance today. We provide primary power for Coast Guard cutters and buoy tenders. We supply stand-by generators for Navy submarine bases. We power submarine docking vessels as well as U. S. Navy LSTs. We propel a fleet of harbor tugs for the U. S. Army. We are even active in the export military market.

Electro-Motive Division. It's just one of the many resources at GM that are committed to providing the latest in tactical and strategic technology–on time and on cost. General Motors Defense. We're your ultimate ally in the fight for dependable, affordable defense. To enlist our aid, write to our Washington, D.C. office: General Motors, 1911 North Fort Myer Drive, Suite 800, Rosslyn, Virginia 22209.

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Editorial Notebook

The New and the Noteworthy

Henry Clarks, the acting director of NASA's Technology Utilization Division, recently called a Technology Utilization conference together in Washington and invited *NASA Tech Briefs'* editors to attend. It was an excellent conference. As editor and publisher of *NTB*, the primary medium for NASA technology transfer, I gained new insight into the involvement of the different members of the NASA Technology Utilization team. Out of the learning process and the discussions came several new ideas for improving *NTB*.

The most immediate need we saw for *NTB* was a better editorial explanation of the technology transfer process, and part and parcel of that was a clear-cut explanation of how you, the reader, can go that step beyond *NTB* and its Technical Support Packages to consultation with NASA's Industrial Applications Centers (IACs) to solve current problems and investigate new opportunities.

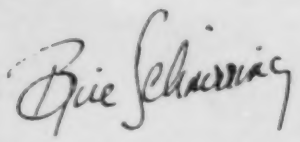
There are 9 IACs that are funded in part by NASA as part of its technology transfer effort. These IACs have the ability of not just searching literally hundreds of data bases, but also of editing that material and offering suggestions on ideas and processes. The problems that the 9 IACs have solved number in the thousands.

What they can do for you may be limited only by your ability to ask the right question. The IACs have done searches for hundreds of Fortune 500 companies. Probably the only reason they haven't done more is because of the difficulty that exists in explaining and marketing their product—information. NASA's huge storehouse of knowledge, including all the tech briefs ever published, is at the IACS, waiting for American industry to avail itself of it.

Effective with this issue, we've attempted to better explain the IACS, how and whom to contact for future ideas and details, by redesigning the Technology Utilization pages that are found in every issue. In this issue, they're on pages 28 and 29.

Also in this issue, you'll find a new tech brief category: Computer Programs. Previously, new computer programs described in *NTB* could be found at the end of whatever tech brief category they referred to, whether physical sciences, mechanics or the like. While the programs will still be referenced under these categories, the actual descriptions of new computer programs will now be grouped together in a separate section. We hope this makes it easier for you to access NASA software and easier for you to utilize *NASA Tech Briefs*.

We've had myriad compliments since we commercialized *NTB*. We appreciate the compliments, but feel we can continue to improve our product. As always, comments and suggestions are not only welcomed, they're solicited. □



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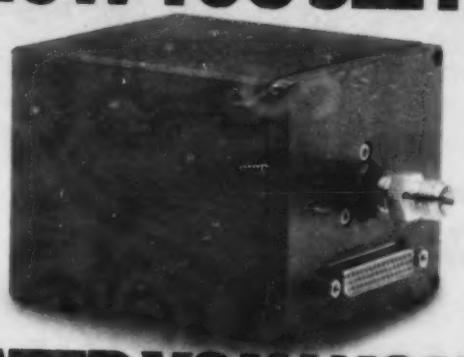

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A versatile discovery

3M Glass Bubbles are hollow microscopic spheres, composed of water-insoluble, chemically stable glass. They are unicellular, and average less than 70 microns—one-fourth the size of a grain of salt.

Originally developed to displace more expensive filler materials, such as resin, *3M* Glass Bubbles were found to greatly improve the performance of end products.

Lower weight and density, and smoother and less porous surfaces are among attributes that make this product ideal in aerospace and hydrospace applications—as well as more traditional fields, including construction, and automotive manufacturing and repair.

The use of *3M* Glass Bubbles as a sensitizer in explosives is one of many specialized applications that have been discovered recently.

3M engineers can help research any special product use you may envision. And the Federal Systems Department will make it easy for you to work with them.

Surer footing

This time of year, in many parts of the country, there is more need than ever to look to 3M for floor matting.

Nomad Matting is recommended for use inside building entrances, in hallways, and in other areas where dirt tracking is a problem.

It is available in six colors and four sizes. One style is designed for outdoor use where oil, grease, or hard chemicals may be present, and still another is designed to cope with snow and slush.

Matting can be ordered with the following official seals and logos:

GSA	U.S. Navy
Postal Service	U.S. Marine Corps
Veterans Administration	U.S. Coast Guard
U.S. Air Force	Air National Guard
U.S. Army	Express Mail

(Contract number: GS-00F-76304)

Electronic protection

A low-cost, flame-retardant, quick-curing powdered resin is now available to provide a coating that will insulate, seal, and protect radial lead film capacitors, ceramic disc capacitors, tantalum capacitors, printed circuits, and other electronic components without adversely affecting their performance.

Called *Scotchcast* Brand Electrical Resins 5300 Series, these products are designed to conformally coat and environmentally protect electronic components.

Information retrieval system

Available immediately from 3M is the newly announced MFB 1100, multi-format plain paper reader-printer.

This unit represents the eleventh generation of microfilm retrieval units from 3M.

Handling all formats, the unit will provide positive prints from both positive and negative microfilm, and will accommodate all reduction ratios from 9× to 47×. The MFB 1100 features a 13×11½-inch screen, 360-degree image rotation, and manual or automatic film advance.

The unit delivers high-quality, inexpensive plain-bond prints from all microforms.

Conclusion

When you need help, think of 3M.

In particular, think of the Federal Systems Department/3M, the organization established nearly two years ago to better serve people in the U.S. Government.

As our name implies, we are dedicated to understanding *your* mission, and *your* particular needs.

Those of us on field assignment are thoroughly trained in government procurement procedures, and are charged with facilitating and expediting your contact with 3M product specialists, research and development scientists, and staff experts who may be able to serve you.

For more information on how to work with the Federal Systems Department/3M, or on these or any of the more than 40,000 products currently available from 3M, write, or call toll-free 800-328-1684 (or in Minnesota 800-792-1072).

Descriptive literature will be mailed to you without cost or obligation. Or, if you wish, a 3M representative will call you for an appointment at your convenience to discuss your particular needs.

Just call **800-328-1684**
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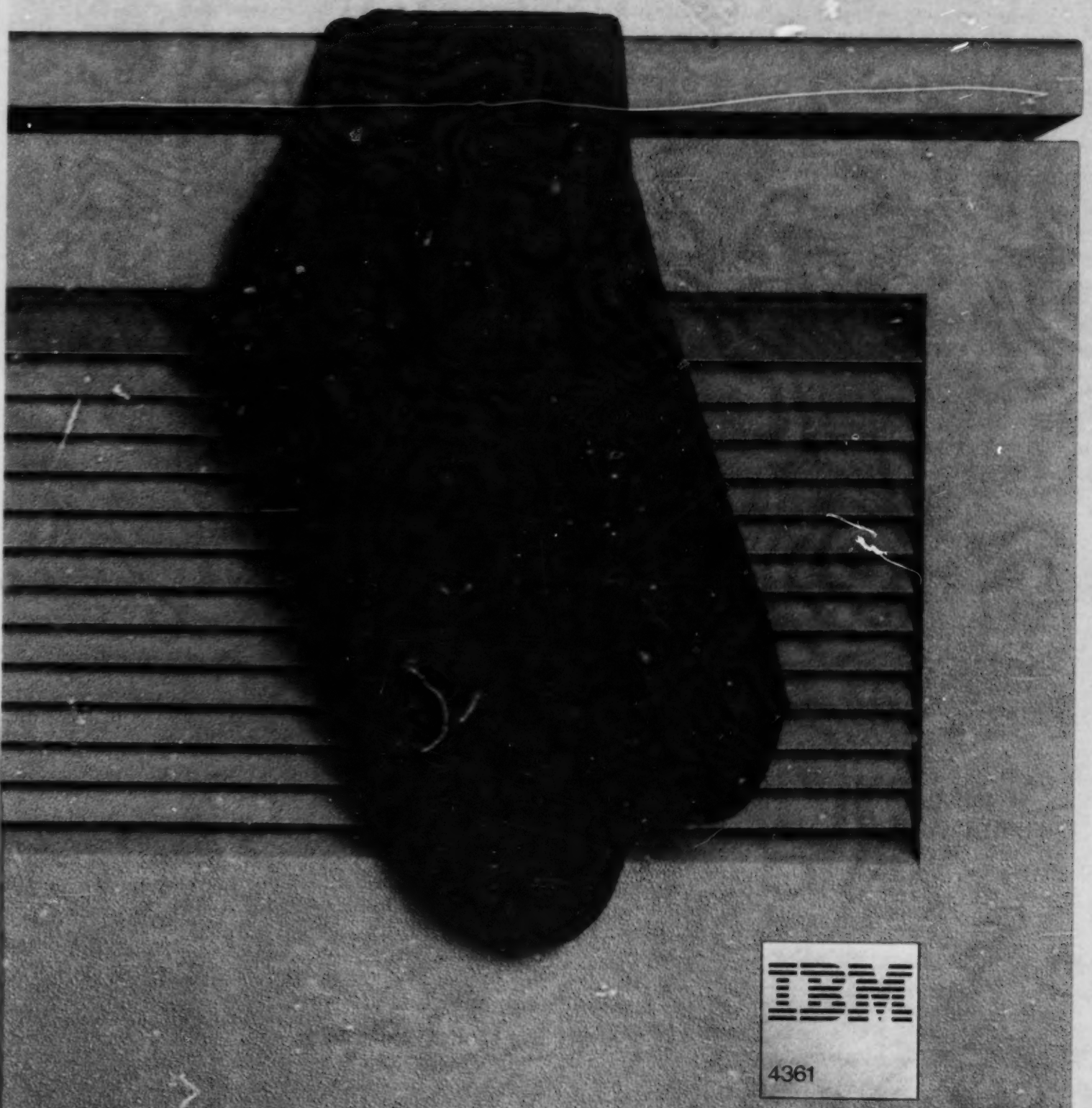
3M

Circle Reader Action No. 422

Here's one supermini that's g



t's gonna knock your socks off.

It's the IBM 4361.

And it's setting new standards for cost-performance. IBM? Supermini? For computational processing? You bet. It'll knock the socks off a centipede.

Speed. The 4361 features a high-speed cache buffer. It has a separate floating-point processor to handle multiplication. And it executes the 70 most-used instructions in the hardware. No wonder the 4361 will turn in a Whetstone that will knock your....You get the idea.

Precision and accuracy. The 4361 has advanced 32/64-bit architecture. It can handle 31-decimal-digit precision. And as for accuracy, IBM's high-accuracy arithmetic facility (ACRITH) includes 22 special floating-point instructions that can be used to process iterative calculations accurately. The ACRITH program notifies you if the accuracy you need can't be maintained.

Ease of use. The 4361 needs no pampering. Install it almost anywhere—in a corner of your office, for example. And the 4361 can run unattended, with no onsite DP specialist.

To make life easier yet, there's the IBM Engineering/Scientific Support System (E/S^3)—a consistent, menu-driven interface for interactive users. E/S^3 is rich in function and offers an open architecture so you can add applications easily. It handles graphics, text and data manipulation. And it supports a wide range of administrative applications.

Attachability. What would you like to attach to your IBM 4361? Lab instruments? Personal computers? ASCII-oriented devices? Are they Multibus* or Unibus**-oriented? Or do they use a serial digital interface? The 4361 welcomes them all. It attaches to IBM and non-IBM devices of all kinds.

Growth path. The 4361 protects your investment. It can be upgraded on your premises over a processing power range of three to one. At low cost and in small steps. If you outgrow even the biggest 4361, you can move up to the IBM 4381 or one of the large 308X or 3090 processors.

There's much, much more. In technology, architecture, service and support. The 4361 is an engineering/scientific computer from head to toe. But hold our feet to the fire. Demand answers to all your questions.

To receive brochures on the 4361 and E/S^3, or to have an IBM marketing representative call, return the coupon.

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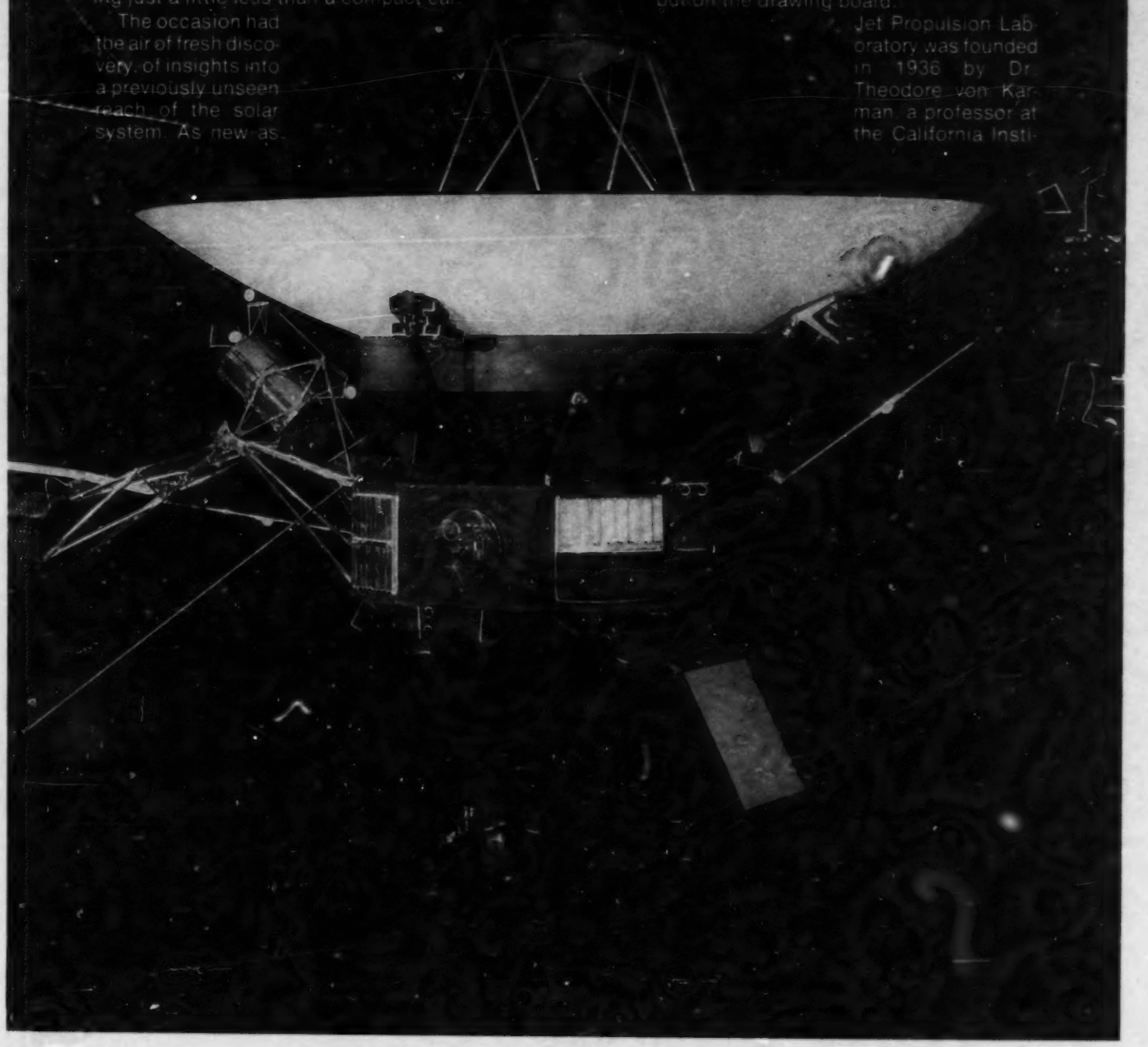
Jet Propulsion Laboratory:
From Rockets to Robotics

For a few days this past January, Pasadena, California, was host to an international gathering reminiscent of the 1984 Summer Olympics in nearby Los Angeles. Scientists, journalists and VIPs from around the world—video crews from Japan and writers from Scandinavia—gathered there to take in the first close views of a new world nearly two billion miles away. The new world was Uranus and our emissary there was Voyager 2, an unmanned spacecraft weighing just a little less than a compact car.

The occasion had the air of fresh discovery, of insights into a previously unseen reach of the solar system. As new as the discoveries were, however, the event had become a common scene at what has been a Pasadena institution for half a century: Jet Propulsion Laboratory.

As NASA's lead center for the unmanned exploration of the solar system, Jet Propulsion Laboratory, better known as JPL, has a long history of designing and building automated spacecraft to probe the mysteries of the planets. But JPL's history extends back before the space age, when rockets were unlikely to be seen anywhere but on the drawing board.

Jet Propulsion Laboratory was founded in 1936 by Dr. Theodore von Karman, a professor at the California Insti-



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California Institute of Technology

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JPL

tute of Technology, and a group of his students and colleagues. At a deserted site just north of Pasadena, they erected a few simple shacks in which they built rudimentary rocket systems. This pioneering work earned the attention of the U.S. government, and in 1938 the CalTech laboratory, later JPL, was awarded the first federal contract for rocket studies.

Early work at the laboratory resulted in the development of solid- and liquid-fueled rockets, and a jet-assisted take-off application for Army aircraft. During the '50s, JPL researchers focused on the development of guided missile systems for the U.S. Army. When NASA was created in 1958, federal jurisdiction over JPL was transferred from the Army to the new civilian agency. Under a NASA contract with, CalTech, JPL was assigned to lead the nation's unmanned exploration of the solar system.

Moving into Space

JPL's history of space-related accomplishments begins with the first U.S. satellite, Explorer 1, which was launched in early 1958. It detected the Van Allen radiation belts that surround the Earth. The Ranger and Surveyor missions of the 1960s mapped and probed the lunar surface, in part to determine the feasibility of landing. These missions ultimately led to the successful Apollo missions and the manned exploration of the lunar surface. JPL's Mariner missions explored the inner solar system and returned images of Earth's nearest neighbors, Mars, Venus, and Mercury. The Viking Mars orbiters and landers of the late '70s transmitted startling images of the red planet's surface and searched for signs of life in the Martian soil. In 1977, JPL's most sophisticated robotic spacecraft, Voyagers 1 and 2, were launched. The twin Voyagers encountered Jupiter in 1979 and Saturn in late 1980 and early 1981, transmitting a wealth of data concerning these two giant planets, their rings and their satellites.

Following the Saturn flyby, Voyager 1 set off on an upward course that will eventually take it out of the solar system toward the star Raselhauge (Alpha Ophiuchus). Voyager 2 was originally to have flown directly out of the solar system as well, but mission planners decided to reroute the spacecraft to accomplish a "grand tour" of the planets. As Voyager 2 swung around Saturn in August 1981, it was deflected into a trajectory that would take it past Uranus in January 1986 and past Neptune in August 1989.

An approximate alignment of Jupiter, Saturn, Uranus and Neptune that occurs only once every 176 years made the addition of Uranus and Neptune to Voyager 2's itinerary a theoretical possibility. Technical developments and spacecraft modifications made the extension of Voyager 2's mission a practical feasibility.

As Voyager 2 set off on its five-year journey from Saturn to Uranus, engineers and scientists at JPL's mission control facility began customizing the spacecraft's systems for the Uranian encounter. New techniques for collecting, processing and transmitting data were developed to compensate for the vastly increasing distance between the spacecraft and its tracking and control stations on Earth.

One of the spacecraft's onboard computers was programmed to preprocess all imaging data before transmitting it to Earth. This innovation involved a JPL-developed form of data compression, which resulted in a 60% reduction in the level of data needed to create images of the Uranian system. It also reduced the time required to transmit the data, allowing more images to be generated and transmitted to Earth.

Another technique, image motion compensation, countered the effects of Voyager 2's 45,000 miles per hour velo-

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city and low levels of sunlight illumination during the encounter to allow the spacecraft's two cameras increased exposure times without causing image smearing. By rotating the spacecraft itself, at rates approaching 1/30th of a degree per second, the cameras were able to obtain clear, close-up images of the Uranian moons. Finally, a technique called arraying was developed to enhance the strength of Voyager 2's signals and the rate of data transmission. Arraying involved electronically linking the antennas at each of the NASA Deep Space Network sites, thereby increasing the strength and quality of the received signals. (The Deep Space Network consists of three tracking stations: one at Goldstone, near Barstow in the Mojave Desert of California, and the others in Robiato, near Madrid, Spain, and Canberra, Australia. All three are equipped with one 210-ft. diarneter antenna and two 85-ft. antennas, plus associated receivers and transmitters. JPL operates NASA's Deep Space Network, which provides receiving and tracking information and controls transmissions to all unmanned, deep space missions.)

By all accounts, Voyager 2's encounter with Uranus was an unprecedented success. The challenges of extremely low light levels (Uranus receives 1/400th as much light from

Voyager Views: A close-up of Jupiter's great red spot and an image of the Saturnian ring system.

the sun as Earth does) and long transmission distances (Uranus is 2 billion miles from Earth) were overcome through technical innovation.

The discovery of ten new moons and at least one additional ring at Uranus were among the initial results of the Voyager 2 encounter. Detailed analysis of the data may take as long as ten years, and a number of other discoveries can be expected. In the meantime, though, JPL's engineers and scientists have a number of other deep space exploration missions in the works.

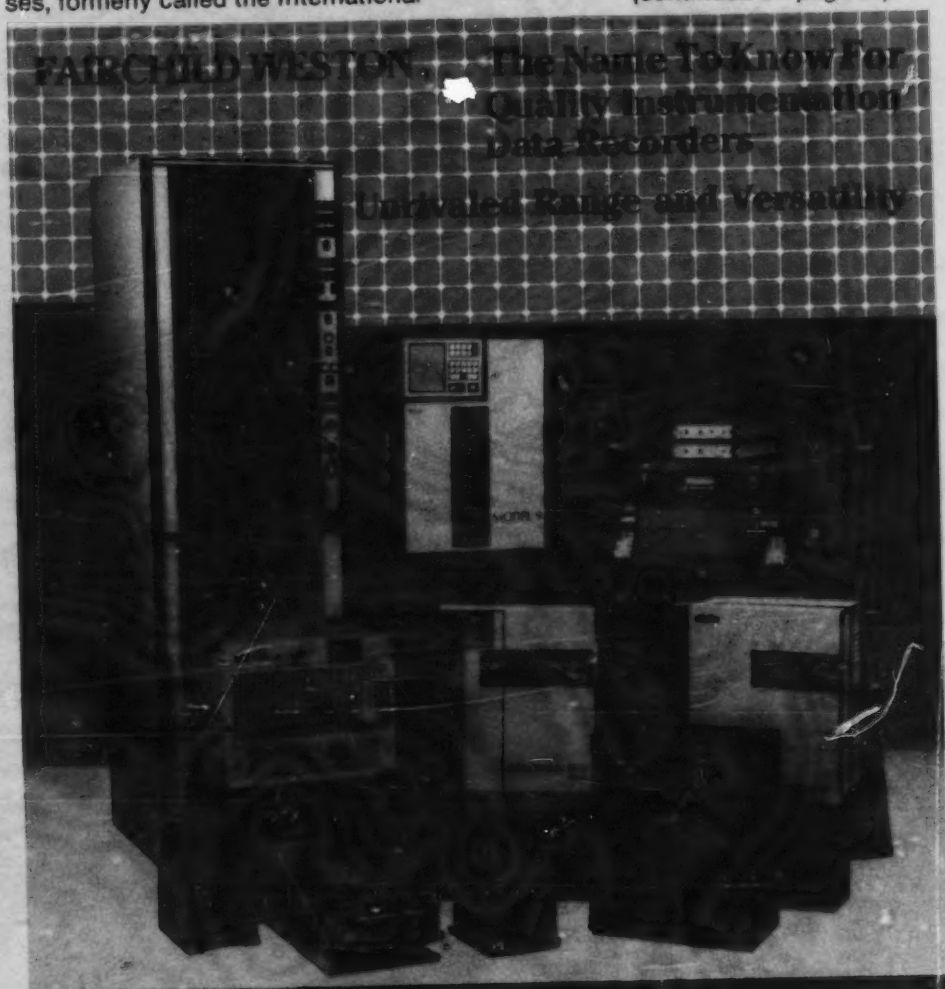
Planetary Preview

The Galileo mission will send an orbiter around Jupiter to explore the planet and its four large moons. Galileo will also drop an instrumented probe into the Jovian atmosphere. The probe will penetrate about 60 miles into the dense cloud cover of the planet, and its instruments will radio back to the orbiter data on the atmosphere, its structure and dynamics. The orbiter will continue to study the stormy clouds of Jupiter and will make extensive photographic and scientific studies of the planet and its moons over an extended period. Like the Voyagers, Galileo was designed, built and tested in-house at JPL.

JPL is also managing the American portion of the joint NASA-European Space Agency Ulysses mission. Ulysses, formerly called the International Solar Polar Mission, will use a boost from the gravity of Jupiter to propel itself over the poles of the sun, probing the poles and the interstellar space that surrounds them. Like Galileo, Ulysses was originally scheduled for a May 1986 shuttle launch. The launch schedules for both spacecraft have been delayed, tentatively until June-July 1987, due to the suspension of the shuttle program.

JPL's Magellan spacecraft, scheduled for a 1988 launch, will orbit Venus and obtain detailed radar images of almost 90% of the planet's sur-

(continued on page 31)



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- EDCS - Error Detection and Correction System with Monitor.
- MODEL 12 B(AN/USH-33(V)1)-High Environmental 10½" reel recorder monitor reproducer.
- MODEL 9 - Transportable 15" reel, microprocessor controlled, very high versatility recorder reproducer.
- ANALOG MULTIPLEXER DEMULTIPLEXER - 16 Channels of Analog Data on 1 Channel of any tape recorder.
- MODEL 15 - High environmental 15" reel, microprocessor controlled, high versatility recorder reproducer.
- MODEL 80 - Portable 14" reel, low cost recorder reproducer.
- MODEL 80TA - Tempest qualified 14" reel, microprocessor controlled, high versatility recorder reproducer.
- MODEL 85 - Portable 14" reel, microprocessor controlled, high versatility recorder reproducer.
- All models to IRIG (RCC) specifications.

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In 1992, we set sail for a New World.

In 1492, a Genoese navigator and an intrepid crew crossed uncharted waters in search of a west passage to India. In the process, they uncovered the vast resources of two continents. And they opened up a new base for exploration, progress, and the hopes of mankind.

In 1992, coincident with the 500th anniversary of Columbus's voyage, we plan to set sail for another New World. That year, or shortly thereafter, the United States and the world will begin benefiting from the first manned Space Station. The Station will be more than another giant step for mankind. It will be our stepping stone to living in new realms, and it will result in thousands of discoveries that will benefit earth.

This New World, free from gravity and atmospheric impurity, will provide that ideal environment for experimentation and production that is impossible on earth. Simultaneously we will have a permanent station for scanning the earth and the heavens—an unparalleled vantage point for predicting weather, aiding agriculture, and understanding the universe.

Of course, like Columbus, we cannot foresee all the benefits ahead. But we do know that we will have a new arena in which to conquer disease, transform the materials of earth, and generate precious energy. The resulting knowledge from countless discoveries will come down to earth for our well-being.

But, unlike Columbus, our craft will be in constant contact with the Old World. Harris Aerospace, as a member of the Rockwell, Grumman and Sperry team, is responsible for the Space Station's communications and tracking system. We are totally committed to this great endeavor, and we bring to the challenge the capabilities and experience necessary for success.

Harris has had 27 years of successful involvement with the kind of space communications and tracking required for the manned Space Station. Our space experience includes programs from Telstar to the Tracking and Data Relay Satellite as well as the manned programs of Apollo, Lunar Module, and Space Shuttle. We are also a leader in the architecture and design of large communication networks.

Now Harris is ready for the Space Station. Over the next years and centuries, the scope of scientific, commercial and technological opportunities and breadth of results are sure to exceed our wildest expectations.

For in 1992, we, too, will be very much like Columbus: carrying the sum of our knowledge into the unknown. And, like him, we, too, shall return with the bountiful gifts of a New World.

HARRIS

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For your information,

our name is Harris.

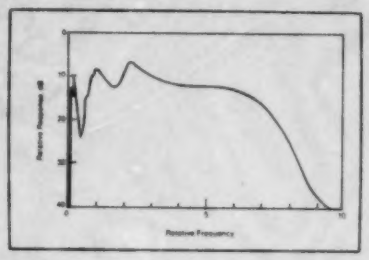
New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 28). NASA's patent-licensing program to encourage commercial development is described on page 29.

Broadband Ultrasonic Transducers

The accuracy of sonar and ultrasonic imaging equipment can be improved through the use of a piezoelectric transducer with a greatly increased bandwidth; this increase is achieved by fabricating the transducer of nonuniform thickness. The transducer can be shaped to respond uniformly over a predetermined band of frequencies and to attenuate strongly the frequencies outside the band (see figure for the frequency response curve of a transducer in which one side of the crystal disk is planar and the other concave). The new transducers may thus make it unnecessary to use signal-processing circuits to compensate for the transducer frequency response or to use auxiliary circuits to modify the frequency spectrum of the voltage applied to the crystal.

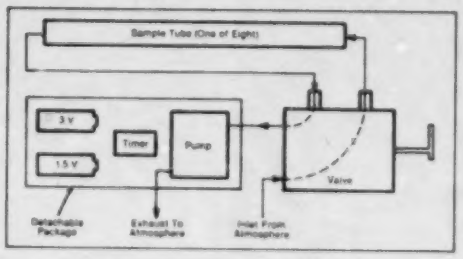
(See page 47.)



Solid-Sorbent Air Sampler

Volatile organic compounds in air are collected for analysis by a portable, self-contained sampling apparatus in which a pump draws air at a rate of 0.1 to 0.5 cm^3/min through glass-lined, stainless-steel sample tubes filled with a porous polymer of 2,3-diphenyl-p-phenylene oxide. When each of the eight sample tubes is placed in the collecting position, high-boiling-point organic compounds are adsorbed onto the polymer, while low-boiling-point organics, O_2, N_2, Ar, CO_2, CO, and H_2O pass through. At the end of the sampling period, the operator turns the valve handle to the next position, thereby exposing a new sample while isolating and protecting the previous sample(s). For analysis, the sample tubes remain in place and are connected through the valve to a standard gas-chromatographic/mass-spectrometric system.

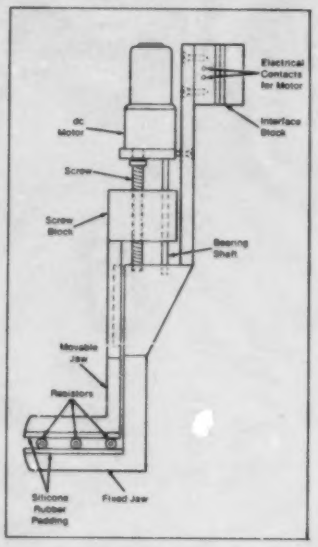
(See page 68.)



Gentle End Effector for Robots

And end effector, designed for use with a Puma (or equivalent) robot arm, handles delicate small parts firmly but gently. It grips such electronic components as resistors, capacitors, and transistors without damaging them and holds them during soldering or other processing. The end effector is driven by a dc motor instead of the usual pneumatic drive. The motor is mounted on the fixed jaw of the effector and drives the movable jaw through a screw block. The jaws are made of steel, and their gripping surfaces are lined with silicone rubber to cushion and, therefore, further reduce the chance of damaging the components. The jaws withstand soldering termperatures greater than 500 °F (260 °C).

(See page 128.)



Ball-and-Socket Mount for Instruments

A ball-and-socket mounting mechanism holds a scientific instrument securely, allows the instrument to be oriented, and minimizes the conduction of heat to and from the instrument. The mechanism includes a stationary base containing part of the spherical socket surface, two jaws that contain the rest of the socket surface, and an adjusting screw. A ball on the instrument sits in the spherical socket formed by the opposing jaws and base. Counterclockwise rotation of the screw closes the socket around the mounting ball. Clockwise screw rotation opens the mechanism by sliding the jaws outward on a dovetail track on the base. The instrument ball can then be disengaged from the open socket, allowing the instrument to be removed.

(See page 78.)

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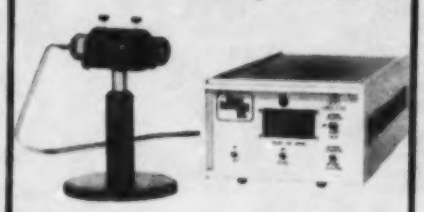
Power Technology Inc.

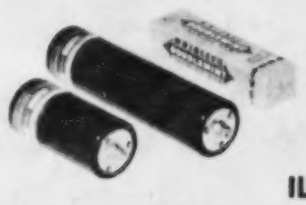
LASER SIMULATOR (eye-safe)



CS100

These convenient, easy to use laser simulators are compact and self-contained. They provide a pulsed 1.06 micron infrared signal source simulating a YAG laser. Because of their portability, they are ideally suited to laboratory or field testing of laser rangefinders, and simulation of laser designators.

LASER DIODE PULSERS



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The ILC produces more average output power for driving laser diodes at 7 to 200ns pulse widths than avalanche or SCR pulsers. Models are available for pulse currents of 1 through 100A. Fast rise and fall times, with internal clock for pulse rates of 1 through 10,000 PPS.

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ILM

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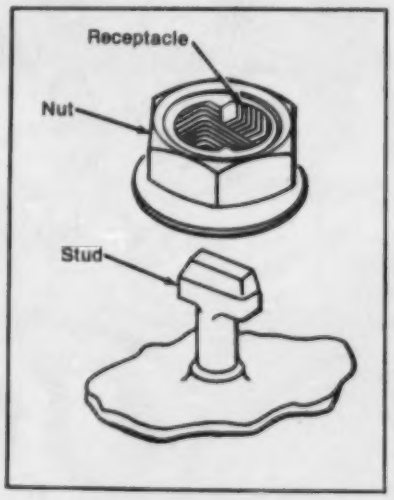
Quick-Connect Heavy-Duty Fastener

A fastener consisting of two mating parts—a T-shaped stud and a receptacle with an external thread and nut—combines the best features of quarter-turn fasteners and threaded fasteners. Like quarter-turn attaching devices, it can be connected and disconnected quickly; like threaded devices, it can be adjusted to a desired preload, withstand high loads, and accommodate a wide range of grip lengths. Used to attach pads to the tracks of tracked vehicles, the fastener prevents pad separation under tension loads and resists loosening under compression loads. It establishes the required prestress within fairly narrow bounds (±25 percent), despite the wide variations of the grip length that is caused by variation in the dimensions of the pad plate (a stamping) and the track shoe (a forging).

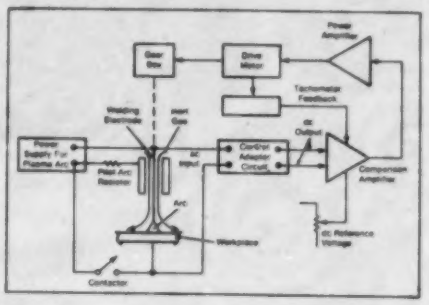
(See page 108.)



Controlling Arc Length in Plasma Welding

A control adapter circuit maintains a constant arc length during the plasma arc welding of irregularly contoured parts. The addition of this circuit to a plasma arc welding machine requires just a few wiring changes. Compared with unmodified machines, plasma arc welders containing the adapter circuit produce welds that are cleaner and require less rework. The circuit samples the ac arc voltage, then half-wave rectifies and filters it to reduce the ripple. The resulting dc measurement signal is applied to a comparison amplifier, which compares it to a reference voltage that represents the commanded arc length. The amplified comparison signal is applied to a power amplifier that drives a motor and gear train to adjust the electrode position and therefore the arc length.

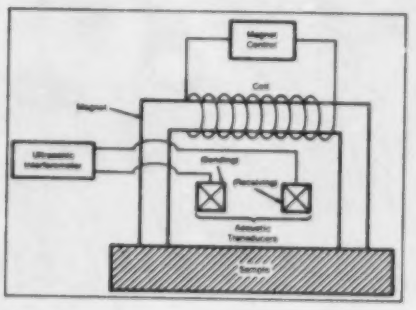
(See page 141.)



Acoustic/Magnetic Stress Sensor

A portable high-resolution acoustic/magnetic stress sensor measures compressive or tensile stresses and stress gradients in steel members quickly and nondestructively. The sensor includes a precise high-resolution acoustic interferometer, transmitting and receiving acoustic transducers, an electromagnet coil and core, a power supply, and a magnetic-field measuring device such as a Hall probe. The stress measurement depends on the shift in acoustic velocity that accompanies the stress-induced change in the magnetic-domain structure.

(See page 112.)



Adjustable Headband for Earphones

A headband, consisting of a pair of cushioned, steel head-clamping spring strips joined by a tensioning screw, holds an earphone and microphone on the wearer's head securely and comfortably. The headband contacts the head lightly but firmly at only two points, eliminating the headaches and soreness caused by conventional models, which clamp on the head over a wide arc. While wearing the headband, the wearer can adjust its width for maximum comfort by tightening or loosening the tensioning screw. The headband accommodates a standard microphone, attached to the first earphone, and a second earphone or an ear mute, either of which would replace the side support, as shown in the figure.

(See page 32.)

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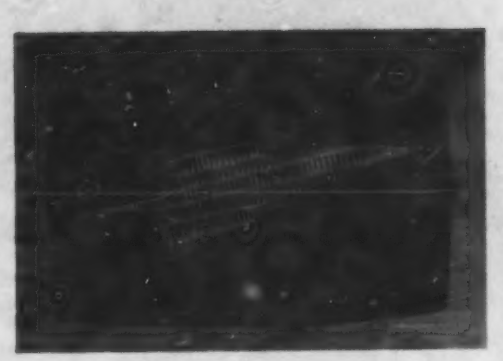

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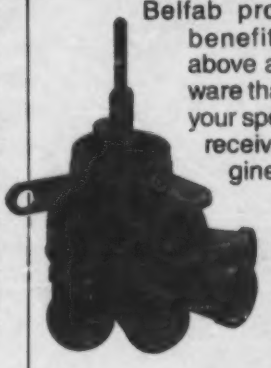

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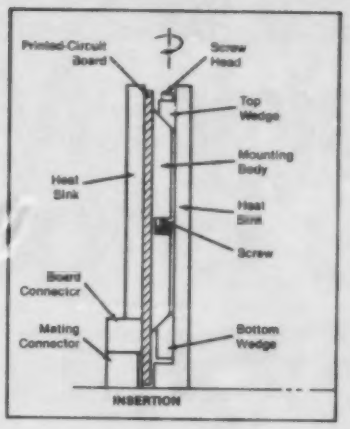
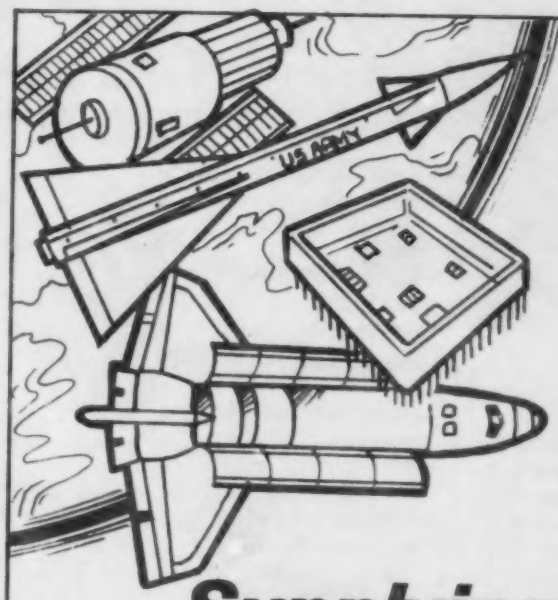
Circle Reader Action No. 301

Ejection Mechanism for Circuit Boards

A mechanism attached to a printed-circuit board partially ejects it from an electronics assembly. The board can then be removed or replaced without using a pulling tool, which could damage circuit patterns and components. Turning a screw in the mechanism produces a jacking force parallel to the connector pins so that they do not become bent or broken as the board is disengaged from its mating connector.

(See page 46.)





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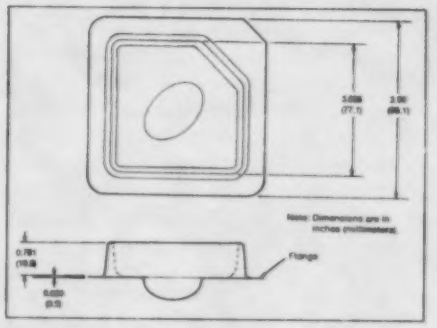
Void-Free Lid for Food Packaging

A folded, flexible plastic lid allows rigid plastic containers holding different levels of food to be sealed at the precise fill level. This lid eliminates air or vacuum pockets above the food and therefore keeps the food fresh and allows compact stacking of partially filled containers. In the sealing operation, the center of the lid is pushed into a rigid plastic cup containing the food to be preserved. As this is done, the lid unfolds and clings to the inside surface of the cup. The rim of the lid is then heat-sealed to the cup. Developed originally for packing dehydrated food for the Space Shuttle missions, this lid might be useful for home food storage and commercial food packaging.

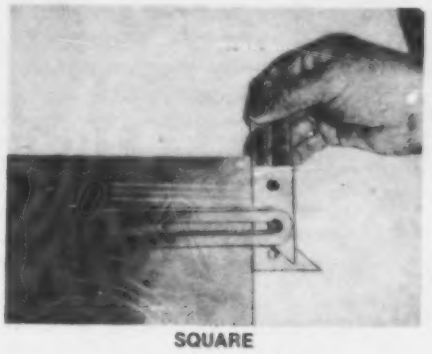
(See page 143.)



Multipurpose Scribing and Drawing Tool

A multipurpose tool speeds up the laying out of patterns on sheet metal, wood, plastic, and paper. The tool consists of two elongated, flat, slotted parts with winglike protuberances that serve as cutters, pencil holders, and supports. It can be carried in a pocket, then quickly assembled for service as a height gauge, pair of dividers, protractor, surface gauge, or square (see figure). The parts are held together by a pair of screws and wingnuts in various configurations, depending on the function required of the tool. The user can thus easily and quickly change the configuration. The tool can be used as a scribe or with a pencil, depending on the material to be marked.

(See page 119.)



SQUARE

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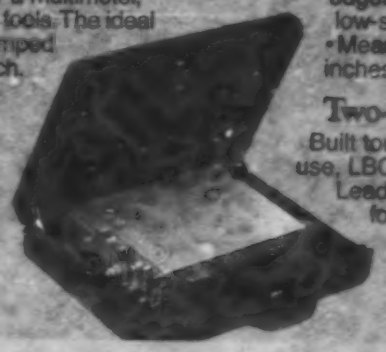

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Circle Reader Action No. 300

JPL

(continued from page 19)

face. Using a synthetic aperture radar system, Magellan will, in effect, see through Venus' thick sulfuric acid and carbon dioxide cloud cover to produce photograph-like images of the surface with a resolution as fine as 1 km. As part of a trend toward reducing the cost of building scientific spacecraft, Magellan will incorporate spare parts from other JPL-built spacecraft, including the Viking orbiters, the Voyagers and Galileo.

A number of other space and planetary exploration missions are on deck at JPL, among them the Extreme Ultraviolet Explorer, which will conduct an all-sky survey of sources of extreme ultraviolet radiation. The Mars Observer mission will be the first installment in a series of low-cost Planetary Observer missions that use existing spacecraft designs and instrument technology to follow up on the investigations conducted by the Mariner, Pioneer and Viking spacecraft. The Mars Observer will focus on the Martian climate and soil.

Still in the planning stages at JPL is the Mariner Mark II-Comet Rendezvous/Asteroid Flyby (CRAF) mission. Mariner Mark II denotes the next generation of NASA's exploratory spacecraft, which will allow the cost-effective study of objects in the outer solar system. Mariner Mark II spacecraft will adhere to a standard yet flexible design that accommodates a variety of instruments and a variety of mission objectives. The CRAF mission, when funded, will utilize a Mariner Mark II spacecraft to rendezvous with Comet Temple II, and then fly alongside it as the comet orbits the sun.

Diversity in Action

While JPL's primary function is deep space exploration—designing and building spacecraft, then tracking and controlling their missions—these are not the only activities in progress there. As its name implies, and as the tech briefs generated by JPL research and development projects testify, a great deal of innovative activity goes on across a broad spectrum of disciplines at the laboratory.

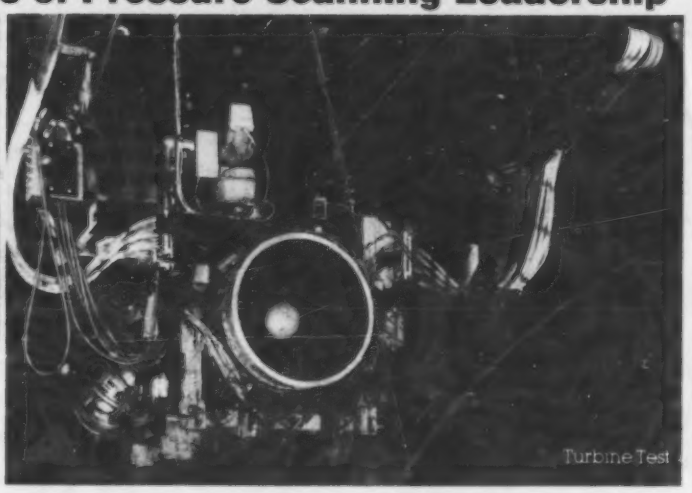
Much of the technology developed in connection with JPL's planetary exploration program is finding secondary applications in the fields of biomedicine, solar energy and robotics. For example, the computer image processing techniques used to generate the enhanced images of the planets are being applied in medical diagnostics. The photovoltaic cells that were developed to provide electric power for orbiting spacecraft have been applied to the generation of electric energy on Earth. The technology associated with automated spacecraft systems has formed a base from which industrial and scientific applications of robotics and machine intelligence can be developed.

As a contractor facility, JPL is something of an anomaly among NASA's field centers. While the U.S. government owns, funds and monitors the facility, it is administered and staffed by CalTech employees, 5000 in all. About 75% of the laboratory's human resources are applied to NASA projects, with the remaining 25% allocated to specific projects coordinated through JPL's Defense and Civil Programs Office which manages the biomedical- and energy-related research, as well as coordinating programs for the Department of Defense.

As diverse as the laboratory is, its most memorable accomplishments are undoubtedly those relating to its planetary exploration projects. Twenty-five years, 7 planets and 43 satellites later, JPL has introduced Earth to its neighbors near and far: Mercury, Venus, Mars, Jupiter, Saturn and now Uranus. Next stop, Neptune. □

Scanivalve Corporation: 30 Years of Pressure Scanning Leadership

Wind Tunnel Test



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Circle Reader Action No. 381

Electronic Components & Circuits

Hardware, Techniques, and Processes

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40 Positive-Index Guiding in CDH-LOC Lasers
40 Bidirectional dc-to-dc Power Converter
42 Video Processor for Transponder Pulses
43 Lithium-Counterdoped Solar Cells
46 Ejection Mechanism for Circuit Boards
47 Broadband Ultrasonic Transducers
47 Correcting for Nonlinearity in a Photodetector
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49 A 25-kW Series-Resonant Power Converter

Adjustable Headband for Earphones

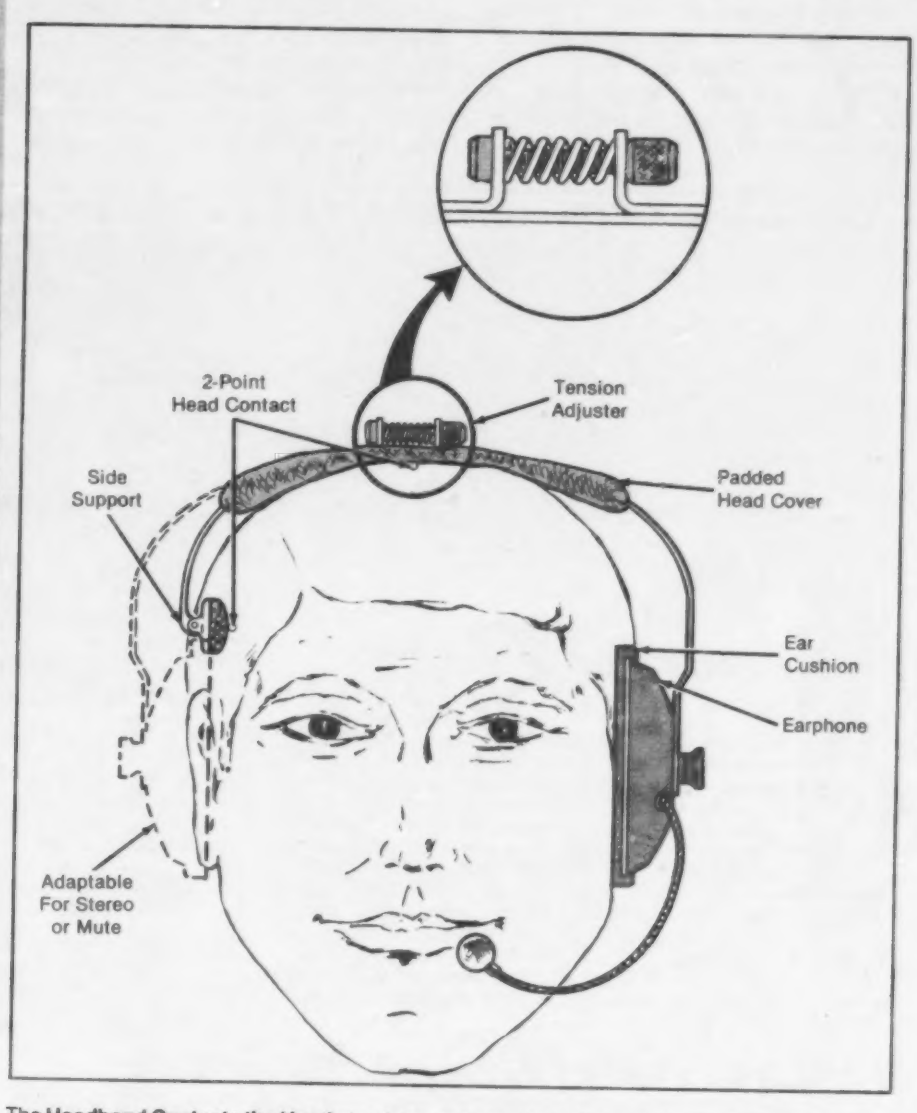
A new handband is designed for comfort and convenience.

John F. Kennedy Space Center, Florida

A new headband holds an earphone and microphone on the wearer's head securely and comfortably. A wearer can easily adjust it for his or her own head size and can readily readjust it for greater comfort without removing it.

Unlike conventional headbands, which are essentially springs that clamp on the head over in an arc, the new headband contacts the head, lightly but firmly, at only two points, eliminating the headaches and soreness often caused by the conventional models. Moreover, the new headband can be adjusted more precisely to the individual's needs. Whereas a wearer would ajust the width of a conventional headband in a coarse way by bending it, the new headband can be adjusted finely by a tensioning device.

The new band consists of a pair of steel head-clamping spring strips joined by the tensioning screw (see figure). A cushioned side support is mounted on the end of one strip, and a cushioned earphone and the microphone are mounted on the end of the second strip. The band is reversible; that is, the earphone can be worn on either the left or the right ear. The side support can be replaced by a second earphone for stereo listening or by an ear



The **Headband Contacts the Head** at only two points; at the top and above one ear and at the padded side support. It accommodates standard earphones and microphones.

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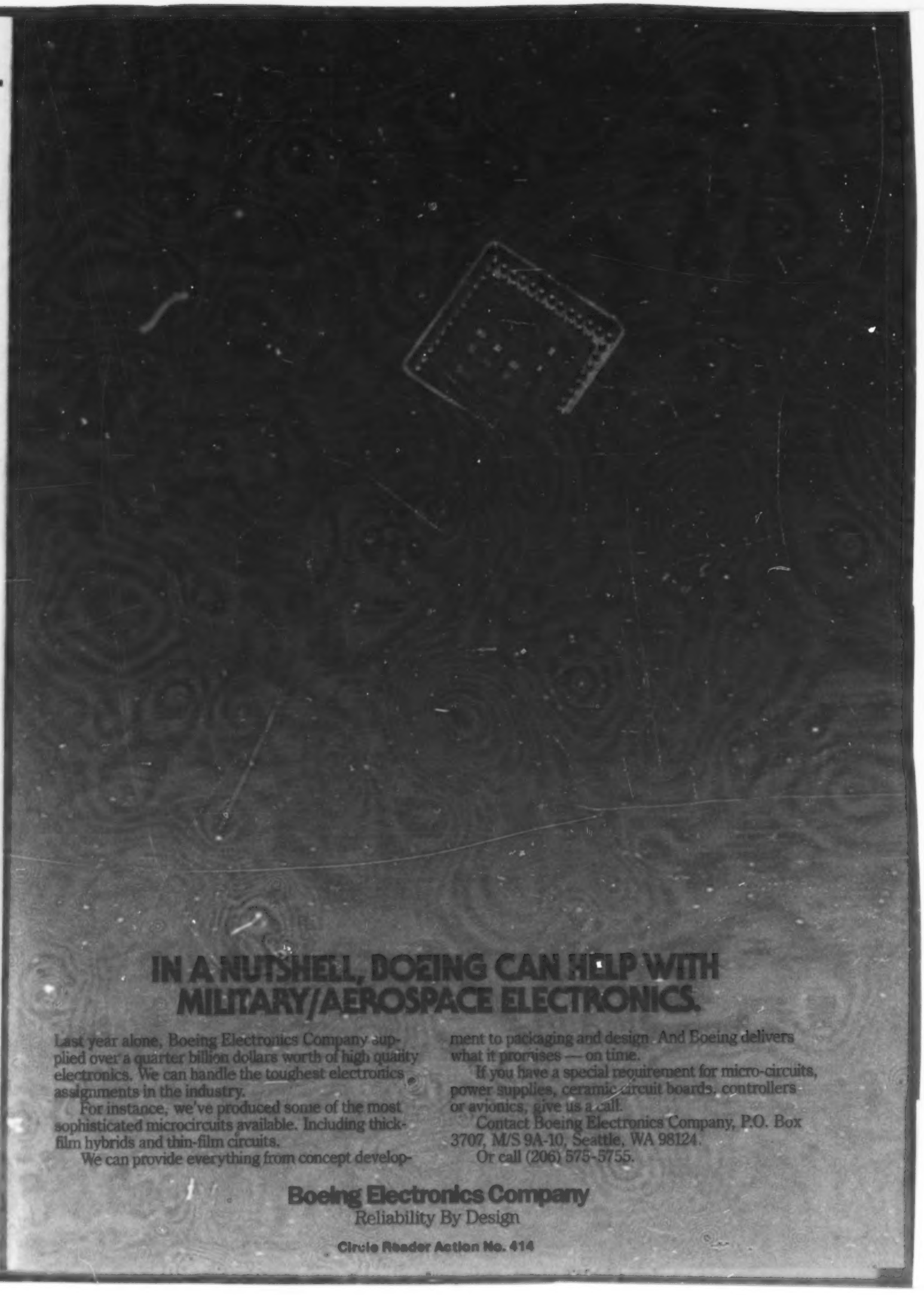

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mute for use in noisy surroundings.

The wearer adjusts the tension, tightening or loosening the knurled-head screw. This screw and a small, compressed coil spring cooperate to slide the head-clamping springs toward or away from each other. The wearer adjusts it while it is still on the head by turning the knurled head, thereby compressing or loosening the spring. Various alternatives to the coil-spring adjuster are available, such as a bidirectional rotatable cylinder on a threaded shaft, a thumbscrew on sliding strips, or a rack-and-pinion arrangement.

This work was done by Pierce C. Toole, Howard E. Chalson, and Stephen Bussey of **Kennedy Space Center.** *For further information, Circle 104 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11322.

Linear Phase Modulator

The circuit suppresses the AM component while providing a matched input impedance.

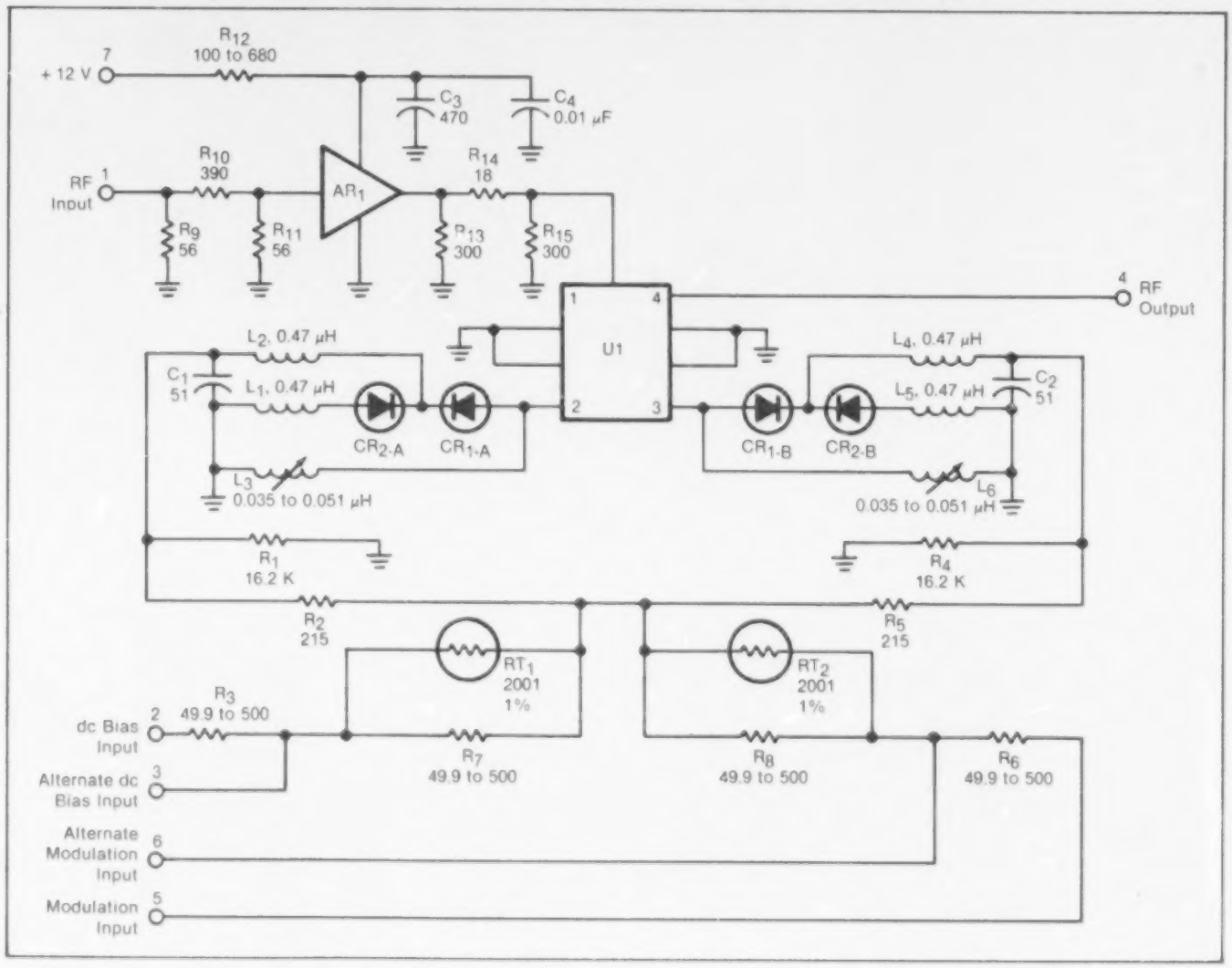
Lyndon B. Johnson Space Center, Houston, Texas

A linear phase modulator combines two shorted resonant circuits with a quadrature hybrid coupler to produce a matched input impedance and eliminate the amplitude-modulation (AM) component. Previous designs created a large AM component along with the phase-modulation component. The circuit, which was used in the payload integrator of the Space Shuttle S-band communications and tracking equipment, should find application in other communications and tracking equipment.

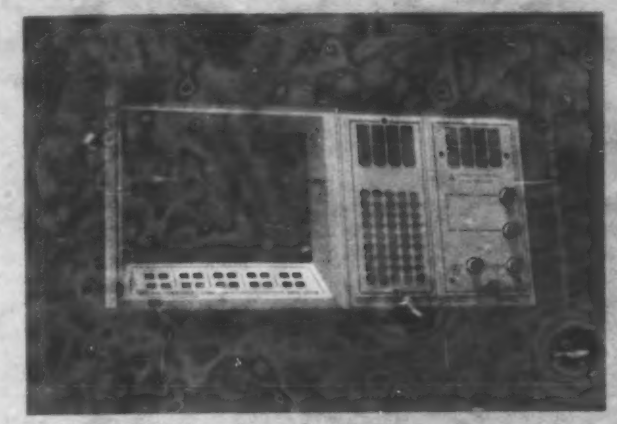
The new phase modulation shown in the figure uses the reflective properties of a series resonant tank to reflect all of the signal except for a small amount in the unloaded Q of the coils and varactor diode. The circuit was designed to meet the following requirements: operation at 320 MHz with the capability of modulating ± 36° within ± 10 percent of the best-fit straight line with an AM component of less than 0.5 percent.

This work was done by Robert H. Hesse of TRW, Inc., for **Johnson Space Center.** *For further information, Circle 33 on the TSP Request Card.*

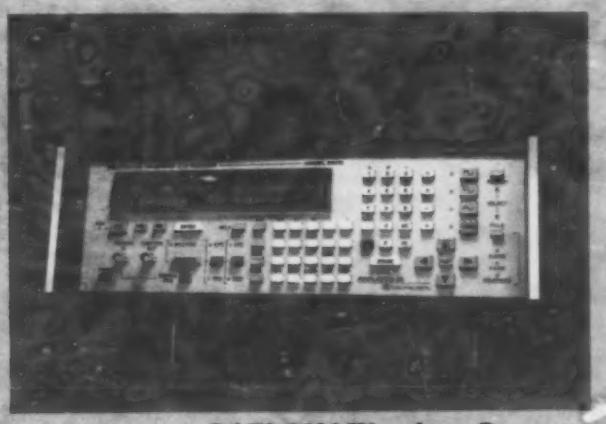
MSC-20555



The **320-MHz Phase Modulator** provides ± 36° modulation while suppressing the AM component. The circuit also eliminates the input mismatch problems because of the matching capabilities of the balanced design using a quadrature coupler.



DATA 6000 Waveform Analyzer



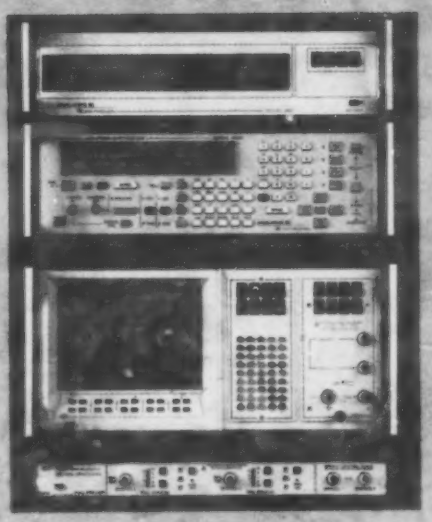
DATA 2020 Waveform Generator

Rule the Waves

Coming...

The DATA 6000 Universal Waveform Analyzer offers the ultimate in signal acquisition and on-board waveform analysis in one unit—without programming. Front panel commands are available for complex waveform operations, such as FFT and Correlation as well as scalar parameters such as Max., Min., Width, Rise, or PK-PK, using the display cursor and crosshair. For specialized measurements, the 6000 can also store analytical routines internally.

- Digitizing Plug-Ins from millihertz to 100MHz sample rates.
- An ultra-high dynamic range digitizing plug-in: 1MHz at 16 bits.
- Simultaneous multi-channel sampling with pre- and post-trigger transient capture.
- FFT (Magnitude and Phase), Convolution, Correlation, Waveform Average, Amplitude Histogram, etc.
- Direct plotter drive for HP-GL compatible plotters.
- Companion Model 681 Flexible Disk Drive for waveform and program storage.
- Full Programmability for ATE via IEEE-488 or RS-232 interface.



Combining the DATA 2020 and DATA 6000 yields an unbeatable system for signal acquisition, analysis *and regeneration*. Capture actual signals with the DATA 6000. They can then be modified or combined with other waveforms and down-loaded into the 2020 for regeneration. What was transient can become repetitive, available on call. Shown above, from top to bottom, are the 681 Flexible Disk, the DATA 2020, DATA 6000 and D-1000 Pre-Amplifier: products which give you the power to rule the waves both coming *and* going.

or Going.

The DATA 2020 Polynomial Waveform Synthesizer provides an unprecedented ability to emulate real world signals, creating desired waveforms from mathematical definitions. Modify the ideal waveforms to add distortion, noise or glitches. Simulate degraded rise times, phase shifts . . . test the limits. Your systems and products must live in the real world. Emulate it with the 2020.

- Direct front panel or remote entry of mathematical equations of the form $Y = f(t)$.
- High-speed waveform generation—up to 25 megapoints per second at 12 bits (100 megapoints at 12 bits, optional).
- Large waveform output memory—up to 512K points, combined with non-volatile storage of hundreds of waveform equations.
- Standard Functions—sine, square, triangle with variable symmetry, plus white noise which can be summed with any signal.
- Arbitrary Mode including point entry, scope draw, and down-loading of the waveform memory.
- Full Programmability for ATE via IEEE-488 or RS-232 interface.

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For additional information Circle RAC No. 432
For a demonstration Circle RAC No. 433

THE SKY WAS THE LIMIT.

AT&T has shattered the information barrier—with a beam of light.

Recently, AT&T Bell Laboratories set the world record for transmission capacity of a lightwave communications system—20 billion pulses of light per second. The equivalent of 300,000 conversations, sent 42 miles, on a hair-thin fiber of super-transparent glass. But that's really getting ahead of the story.

Actually, the 20-gigabit record is only one of a series of AT&T achievements in the technology of lightwave communications.

But what does that record mean?

The Light Solution To A Heavy Problem

All of us face a major problem in this Information Age: too much data and too little information. The 20-gigabit lightwave record means AT&T is helping to solve the problem.

For data to become useful information, it must first be quickly, accurately and securely moved to a data transformer—a computer, for instance. Getting there, however, hasn't always been half the fun.

Metallic pathways have a limited transmission speed, sensitivity to electrical interference and potential for interception—factors that reduce the effectiveness of today's powerful computers. Factors that are eliminated by lightwave communications technology.

Ten Goes Into One 20 Billion Times

Three primary components make up any lightwave communications system. On the transmitting end, a laser or light-emitting diode; on the receiving end, a highly sensitive photodetector; and in the middle, super-transparent glass fibers we call lightguides.

Installing these fibers is a major cost of a lightwave communications system. So, once installed they should stay put—increased capacity should come from fibers carrying more, rather than from more fibers.

Which brings us to the 20-billion bit-per-second story—about experimental technology that has the potential to upgrade installed fiber to meet any foreseeable capacity needs.

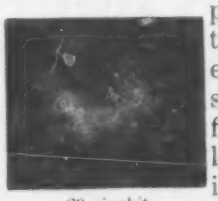
Using new, sophisticated lightwave system components, we multiplexed (combined) the outputs from 10 slightly different colored 2-billion bit-per-second laser beams into a single 20-billion bit-per-second data stream.

Playing Both Ends Against The Middle

But, let's start at the beginning—the 10 distributed feedback laser transmitters.

These powerful semiconductor lasers can be grown to produce light of different, but very precise, wavelengths. The lasers we used transmitted in the 1.55 micron (infrared) range, with only minuscule fractions of a micron between their wavelengths. The purity and stability of the beams let us pack their ten colors into the most efficient transmitting region of our single-mode, silica-core fiber.

To make the original 10 beams into one, a fiber from each laser was fed into a new lightwave multiplexer—a prism-like grating that exactly aimed each beam into the single transmission fiber. Over 42 miles later, a second grating fanned the beam back into its original 10 colors for delivery to 10 exceptionally sensitive avalanche photodetectors—receivers that convert the light pulses back into electrical signals and amplify them many times.



20-gigabit multiplexer

A similar avalanche photodetector was the receiver when AT&T Bell Laboratories set the world record for unboosted lightwave transmission—125 miles at 420 million bits per second.

From Sea To Shining Sea

System capacity is important. But system reliability is vital. Especially when the system is going under 10 thousand miles of water—and is expected to last for 25 years.

AT&T is going to build the first lightwave communications system under the Atlantic Ocean. A similar system is planned for the Pacific. In 1988, laser beams traveling through two pairs of glass fibers will carry the equivalent of 37,800 simultaneous conversations overseas, underwater, from the U.S. to Europe and the Far East.

AT&T has manufactured and installed lightwave systems—as large as the 780-mile Northeast Corridor and as small as single-office local area networks—containing enough fiber to stretch to the moon and back. And the capacity of each network is tailored to meet the unique needs of its users.

Systems being installed in 1985 will be able to grow from 6,000 up to 24,000 simultaneous conversations on a single pair of fibers.

AT&T is meeting today's needs with lightwave systems that are growable, flexible and ultra-reliable. And anticipating tomorrow's needs with a whole spectrum of leading-edge lightwave communications technologies.

AT&T

The right choice.

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Cross-Array Antenna With Switched Steering

Selected phase shifting of the feeds to antenna elements aims the antenna beam.

Lyndon B. Johnson Space Center, Houston, Texas

The aiming direction of a S-band cross-array antenna proposed for Space Shuttle use would be controlled in two dimensions by double-pole, double-throw switches in the antenna feeds. The switches would control the phasing of the antenna elements by transposing transmission-line delay elements between the feeds to pairs of elements located on opposite sides of the antenna.

The figure shows a 5-element antenna with 4 switches, capable of 16 different beam directions. The two switches in the feeds to antenna elements A and B control the horizontal component of the beam direction; the switches in the feeds to C and D, the vertical.

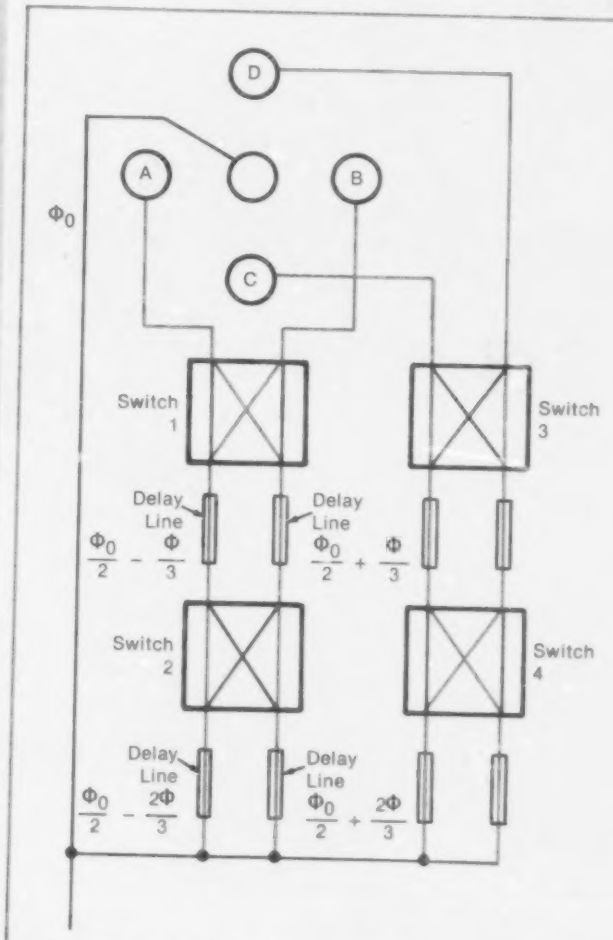
The angular separation between aim directions is determined by the spacing between the antenna elements and the amount of phase shift from element to element at the operating frequency. Except for a small correction due to the directionality of the radiation pattern of the individual elements, the maximum gain of the antenna would occur in the direction in which all the elements contribute in phase. By turning off either or both of the outer pairs of elements, the beam pattern can be broadened along one or both axes.

Each of the phase-changing switches has a 0.2-dB insertion loss. Since only the phase differences between the elements (but not the absolute phases) are significant, one element may be fed directly. Therefore, the total power loss is minimized by feeding the center element directly, since this element receives the feed of highest amplitude.

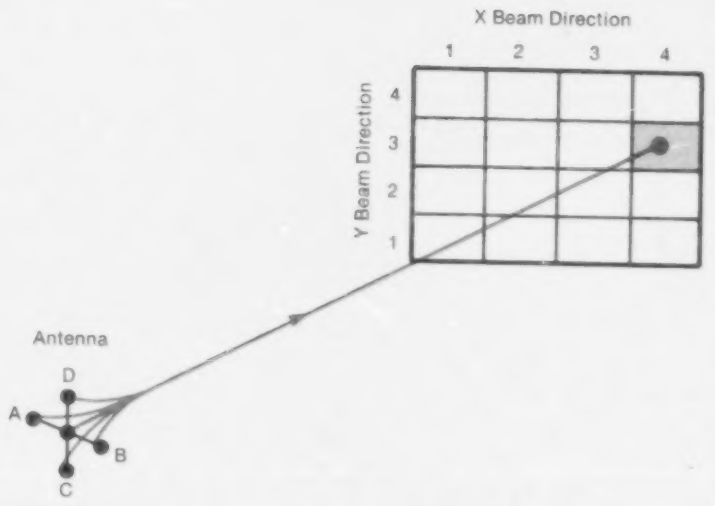
The number of switches and delay lines determines the number of different aim directions that will be available. For n switches, there can be up to 2^n aim directions, provided that appropriate delays are selected. While the example of the figure uses two switches in each feed axis, more or fewer than two can be used. Similarly, the same principles can be applied to antennas with additional elements along each axis.

For a configuration with n switches, an n-bit binary number suffices to specify the aim direction: Each bit represents the setting of one switch. A microprocessor could be used to control the switches.

This work was done by Richard S. Iwasaki of Axiomatix for **Johnson Space Center.** *For further information, Circle 55 on the TSP Request Card.* *MSC-20889*



Switch 1	Switch 2	X Beam Direction	Element A Phase	Element B Phase
| |	| |	1	$\Phi_0 - \Phi$	$\Phi_0 + \Phi$
×	×	2	$\Phi_0 - \Phi/3$	$\Phi_0 + \Phi/3$
| |	×	3	$\Phi_0 + \Phi/3$	$\Phi_0 - \Phi/3$
×	| |	4	$\Phi_0 + \Phi$	$\Phi_0 - \Phi$



The **Five-Element Cross-Array Antenna** is shown in a 4-switch configuration. The table shows the phases (Φ's) obtained at elements A and B by setting switches 1 and 2. A similar table applies to switches in the feeds to elements C and D. For the switch settings shown in color, the antenna aims toward the shaded region in the perspective drawing.

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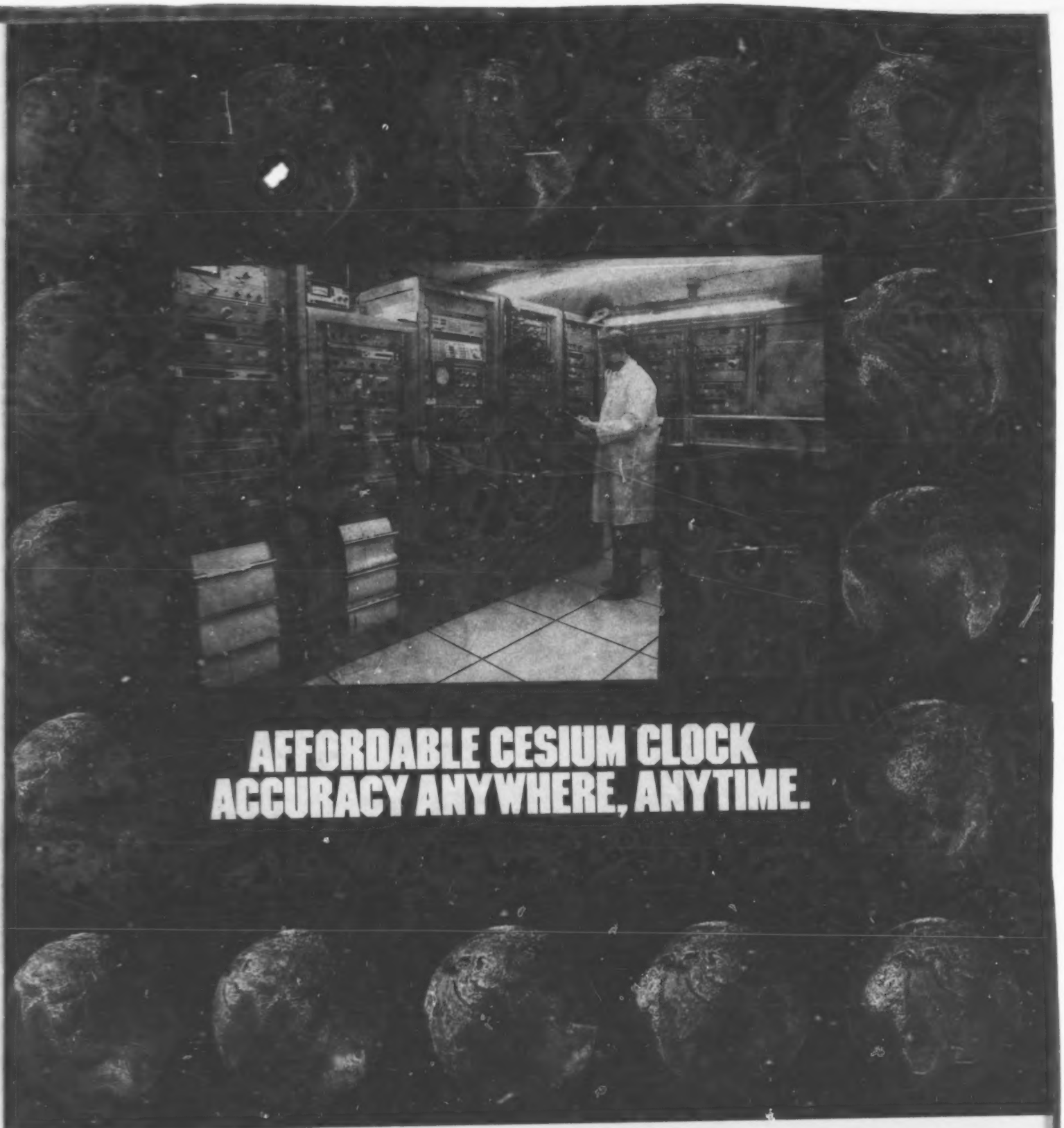

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Circle Reader Action No. 354

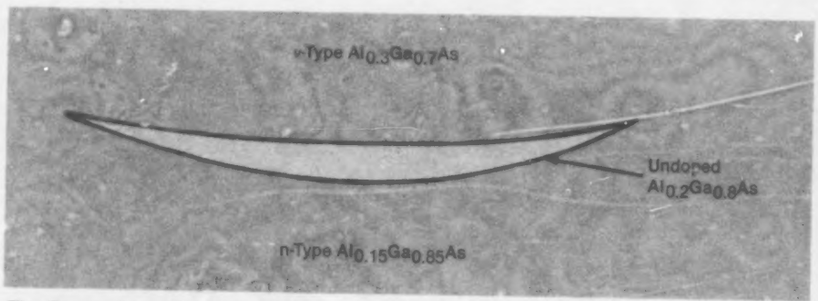
Positive-Index Guiding in CDH-LOC Lasers

A nonabsorbing passive region has beam-guiding capability.

Langley Research Center, Hampton, Virginia

A previous approach to a nonabsorbing-mirror (NAM) constricted-double-heterojunction, large-optical-cavity (CDH-LOC) laser involved passive regions formed by etching and regrowth. Lateral mode control was to be provided in the passive region by lateral thickness variations of the guide layer. However, if the guide layer has the same shape in the passive region as in the active region (i.e., minimum thickness in its middle tapering laterally to larger thicknesses), light will be quickly dispersed in the passive region since the result is essentially an antiguiding structure without gain.

A new technique for providing positive-index guiding in the passive sections of NAM-CDH-LOC lasers consists of having two layers regrown: (1) a convex-shaped layer of an index of refraction close to that of the guide layer and of material that does not absorb the light generated in the active portion of the CDH-LOC structure and (2) the *n*-type $Al_{0.3}Ga_{0.7}As$ burying material (see figure). The convex-lens-shaped $Al_{0.2}Ga_{0.8}As$ layer (see figure) provides positive-index guiding in the passive region. That occurs while the guide layer keeps the same shape in both the active and passive regions. By varying the Al concentration and thickness of the regrown convex-lens-shaped layer, beam shaping can be achieved. The convex-lens-shaped layer could be of any material (for example, AlGaAs or InGaAsP) as long as its index of refraction is close to that of the guide layer so as to allow light spreading from the guide layer into the convex layer and as long as it does not absorb the light generated in the active section.



The Convex-Lens-Shaped Layer has a refractive index higher than that of the surrounding material so that it serves as an optical waveguide.

A semiconductor laser incorporating these principles was fabricated by sequential liquid-phase epitaxy deposition onto the surface of an n+-GaAs substrate wafer. After chemical etching and regrowth of the appropriate layers to obtain the convex-lens-shaped configuration shown, individual laser chips were formed from the substrate wafer by cleaving through the burying region. A maximum output power of about 1.5 W was obtained with 100-ns pulses at a 1-kHz rate. This is about four times more power than is achieved for devices of this type not incorporating the passive region.

This work was done by Dan Botez of RCA Corp. for **Langley Research Center.** *For further information, Circle 100 on the TSP Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the RCA Corp., Princeton, NJ 08540. LAR-13312

Bidirectional dc-to-dc Power Converter

A solid-state, series-resonant converter would use high-voltage thyristors.

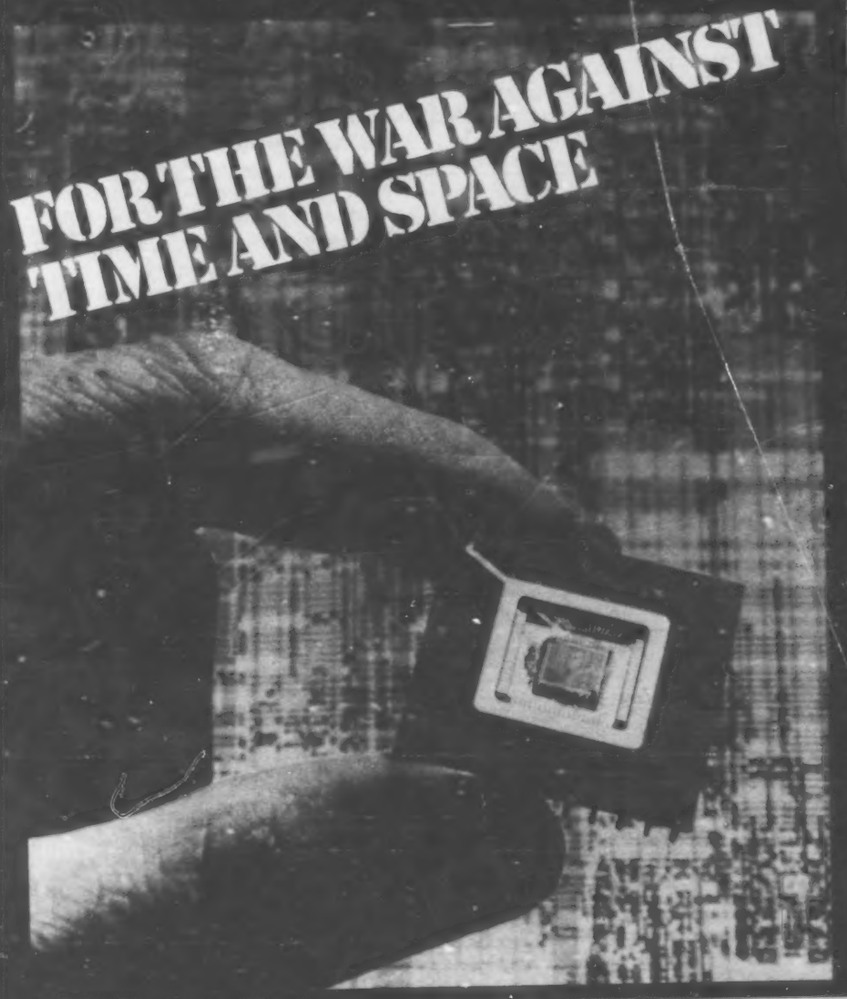
Marshall Space Flight Center, Alabama

A conceptual solid-state, series-resonant dc-to-dc power converter would be used either to convert high-voltage, low-current dc power to low-voltage, high-current power or the reverse. It takes advantage of newly-available high-voltage thyristors to provide better reliability and efficiency than do traditional converters that use vacuum tubes as power switches: Vacuum tubes have short lifetimes, and the power required to heat their filaments reduces conversion efficiency.

The new circuit uses no rotating machinery, such as the motor/generator sets used in some converters. Having neither moving parts nor vacuum tubes, the new converter should be essentially maintenance free and should provide greatly increased mean time between failures. Converters of the new type should be attractive in industrial applications whether or not bidirectional capability is required.

The converter would be built of ten modules in parallel, each carrying a tenth of the total power. Except for the need to use pairs of thyristors in series on the high-voltage side, the high- and low-voltage sides of the circuit are topologically equivalent (see figure). The only other things that distinguish the two sides of the circuit are the asymmetry in the turns ratios of the two transformers and, of course, the voltage and current ratings of the components.

In one mode, the converter would transmit power from the high-voltage side (4,000 to 5,240 V) to the low-voltage side (140 V). The converter could deliver as much as 120 kW to the low-voltage side in



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Circle Reader Action No. 449

HUGHES
AIRCRAFT COMPANY

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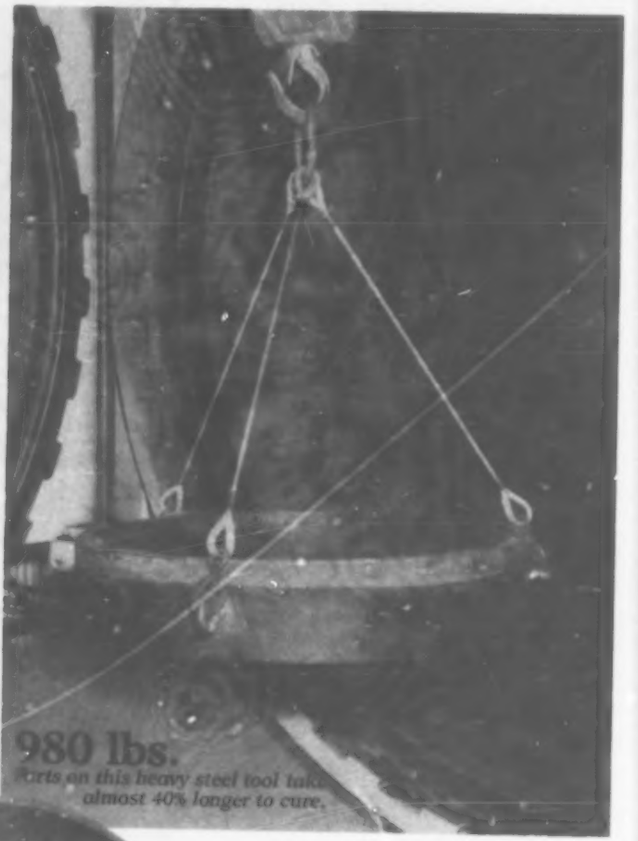
Industrial Electronics Group

Aerojet weighs speed, ease, savings and safety of ToolRite vs. metal tooling

7 lbs.
his ToolRite fixture simplifies handling, permits snap curing.

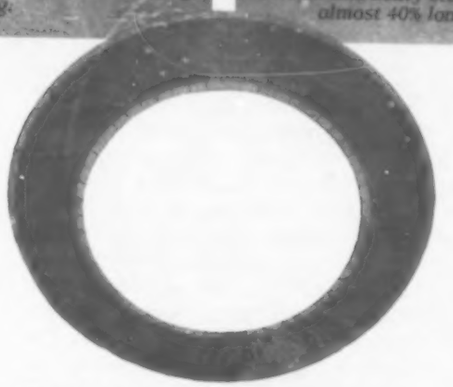


980 lbs.
arts on this heavy steel tool tak almost 40% longer to cure.

Steel tooling can put a burden on a development schedule, and on the corporate bankroll, as well as on the people who have to lug the heavy fixtures in and out of an autoclave.

This is what Aerojet Strategic Propulsion Company is finding as it studies the advantages of a new prepreg composite tooling system–the ToolRite System, from Fiberite.

Its study is part of an ongoing effort–as a primary contractor of solid propellant rocket motors–to maintain leadership in the use of advanced composite materials.



For components such as this flexseal shim for a rocket motor exit cone, Aerojet projects faster prototype development and greater dimensional stability–in addition to tool room, production floor and capital cost advantages.

"We're looking at tooling methods and materials more compatible with the materials we design for and the components we produce," says Paul Vasterling, in charge of advanced tooling concepts at Aerojet.

> ***"We're looking at tooling that's more compatible with the materials we design for and produce."***
>
> *Paul Vasterling*
> *Manager*
> *Advanced Tooling Concepts*

Potential benefits of the ToolRite System include lower scrap rate, easier validation, and averting the need for an additional autoclave.

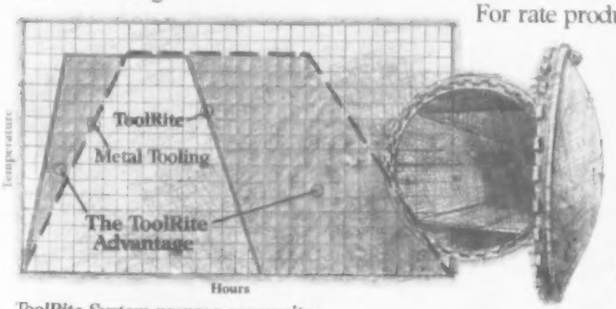
ToolRite: the new way to mold prepregs– with a tool made from prepregs

"But, looking at the big picture, from the drawing board to the finished part," says Ritch Hollingsworth, Senior Manufacturing Engineer, "the main advantage is speed."

First, by allowing Aerojet to build tooling for its prototype parts on plastic-faced plaster masters, the ToolRite System helps trim down the waiting time for tooling late in the project schedule. "It's nice to be able to get a tool 3 or 4 weeks quicker," Hollingsworth says.

> ***"Looking at the big picture ...the main advantage is speed."***
>
> *Ritch Hollingsworth*
> *Senior Manufacturing Engineer*

Reducing tool mass 98%, compared with the steel tooling, allows Aerojet to greatly reduce its ramping and curing times, opening the opportunity for snap cure resin systems. Snap curing brings a tool and part very rapidly up to a critical temperature, at which the system will cure quickly. Steel tools, slow to heat up because of their mass, prolong the exposure of the resin system to lower temperatures and allow it to degrade.



ToolRite System prepreg composite fixtures absorb heat quickly and evenly. This permits snap curing, not possible with steel tools. Shorter cure cycles save on tool inventory, make better use of work force, and may avert the need for an additional autoclave.

The ToolRite System permits low temperature cure on a plastic-faced master and free-standing post-cure. Part validation covers the tool and plaster master as well.

As a result of shorter cure cycles– perhaps as much as 40% shorter– you can get your tools back into use faster, and not tie up the autoclave so long.

Then there is the money ToolRite saves you in handling equipment– carts and cranes. The added safety of lighter tools. And easier, more efficient storage.

For rate production, you can pull additional tools from the ToolRite plaster-faced master economically, with fewer validation steps than when you have to re-machine a new metal tool. (Free-standing post-cure, possible with ToolRite, preserves your plaster master for repeated use.)

Dimensional stability compared with metal tooling is another big advantage. Because the ToolRite System prepregs follow the same heat-up/cool-down curves as the parts curing on them, you can virtually eliminate parts distortion and cure stress.

Compared with wet lay-up, ToolRite prepreg composite tooling means: less labor, less mess and hazardous fumes, greater control of resin content and fiber placement, longer open time, and improved vacuum integrity for up to 500% longer tool life.

Using the ToolRite System is a thoroughly documented procedure, backed by complete factory support from Fiberite. May we arrange a technical briefing for your management, and a shop floor demonstration? Call Kris Ralph at (714) 639-2050 and describe your project. Or send this coupon.

☐ Please send me a *copy of your brochure showing step-by-step tool fabrication procedures using ToolRite Prepreg System.* I am considering ToolRite materials for the following areas:

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☐ *Military Aircraft*	☐ *Recreational*
☐ *Helicopters*	☐ *Thermoforming*
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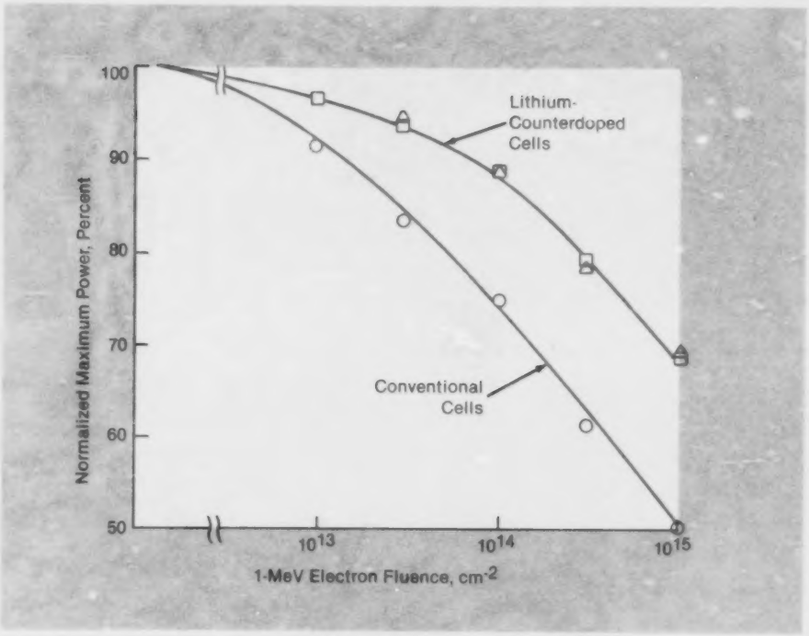


The **Performances of Lithium-Counterdoped and Conventional** cells are compared after irradiation with 1-MeV electrons.

annealed at a temperature of 100° C. The conventional silicon cells now used in space require annealing temperatures of 400° C, or higher, to remove the radiation-induced degradation. Components of solar-cell arrays now used in space, such as adhesives, degrade irreversibly at this high temperature and will not degrade at 100° C. Thus, the present lithium-counterdoped solar cell offers the potential for in situ annealing in space, a process that would increase the electrical power available from the solar-cell array during its use in space missions subject to the degrading particulate environment of space.

This work was done by Irving Weinberg and Henry Brandhorst of **Lewis Research Center.** *Further information may be found in "Increased Radiation Resistance in Lithium Counterdoped Silicon Solar Cells." To obtain a copy, Circle 6 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 29].
LEW-14177

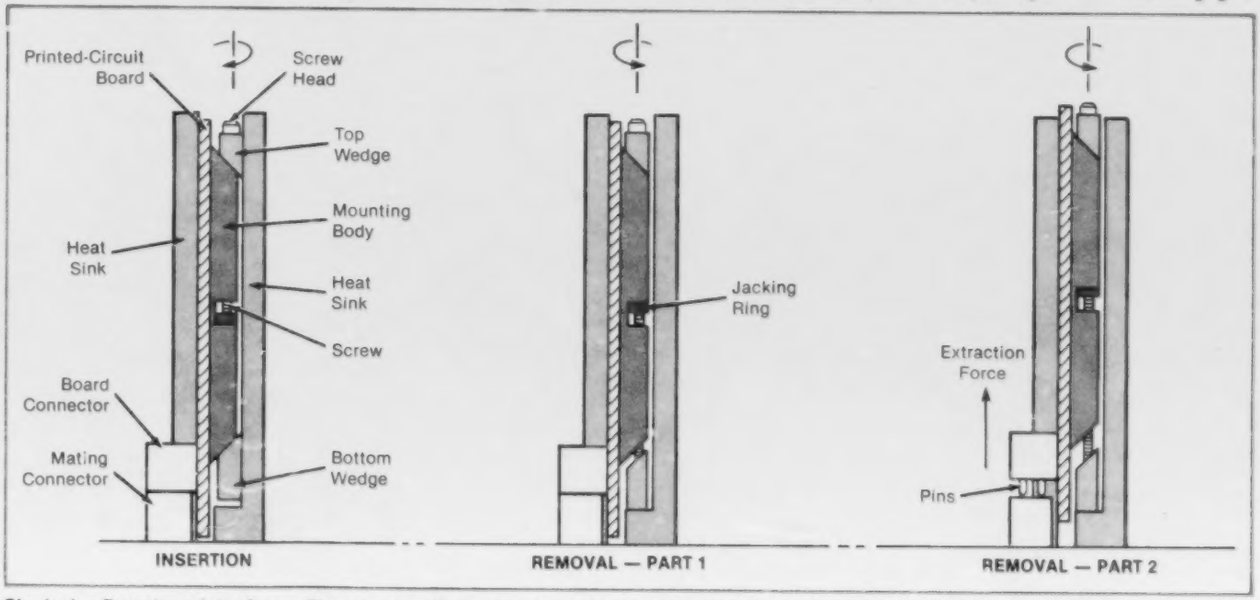
Ejection Mechanism for Circuit Boards

Damage to connectors is reduced and special tools are not needed.

Lyndon B. Johnson Space Center, Houston, Texas

A mechanism attached to a printed-circuit board partially ejects the board from an electronics assembly so that an operator can remove it for repair or replacement. A pulling tool, which could damage circuit patterns and components, is unnecessary.

A screw in the mechanism is turned to produce a jacking force that disengages



Clockwise Rotation of the Screw Tightens the Wedges against the mounting body and the right heat sink. Counterclockwise rotation of the screw drives the bottom wedge downward and the jacking ring upward, pulling the pins away from the mating connector.

the board from its mating connector. The force is parallel to the connector pins so that they do not become bent or broken. When disengaged, the board protrudes from the assembly and can readily be grasped by the operator.

The retainer/extractor screw, along with top and bottom wedges, is inserted in a mounting body, which is crimped onto the circuit board (see figure). To fasten the circuit board in a board frame, the operator inserts the board in the frame between two heat sinks, then turns the screw clockwise. The screw motion forces the wedges toward each other and against the wedging surfaces on the mounting body. This pushes the board against the left heat sink, and the wedges against the right heat sink, thereby locking the board in place and assuring thermal contact between the board and the heat sinks.

To remove the board from the frame, the operator turns the screw counterclockwise. This action drives the wedges away from the mounting body. Continued turning of the screw thrusts the bottom wedge against the frame and pushes the jacking ring upward against the mounting body. The ring thus raises the circuit board away from the frame and disengages it from the connector.

This work was done by Takeshi L. Houff and Douglas Shinno of Hughes Aircraft Co. for **Johnson Space Center.** *For further information, Circle 70 on the TSP Request Card.*
MSC-20763

Broadband Ultrasonic Transducers

A new geometry spreads out the resonance region of a piezoelectric crystal.

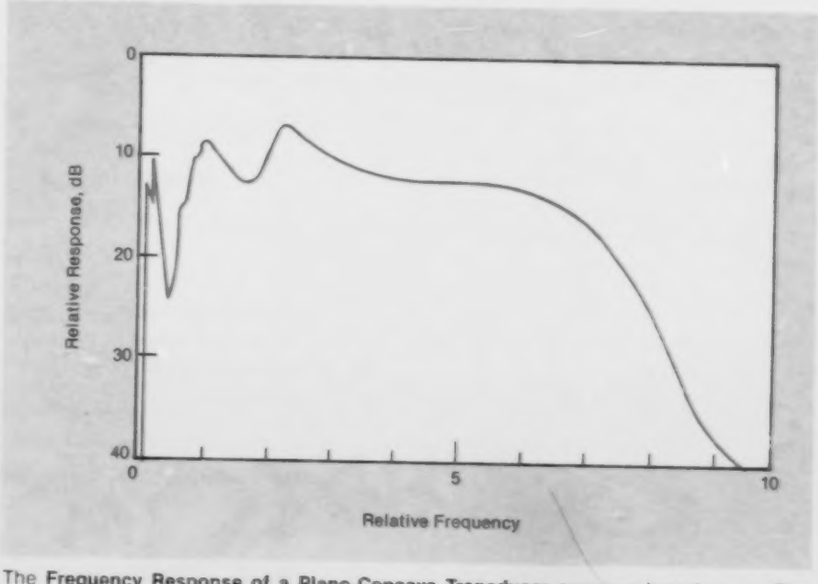
NASA's Jet Propulsion Laboratory, Pasadena, California

The bandwidth of a piezoelectric transducer can be greatly increased by fabricating the transducer with a nonuniform thickness. The greater bandwidth improves the accuracy of sonar and ultrasonic imaging equipment.

A conventional piezoelectric transducer consists of a crystal disk with metal films on its two flat, parallel surfaces. Applying an alternating electrical potential to the films expands and contracts the crystal rapidly so that it launches compressional elastic waves into the material around it. With its parallel faces, the crystal resonates at a narrow range of frequencies, and the ultrasonic waves it sets up in the surrounding medium have essentially the same narrow range.

In the new transducer, the crystal surfaces are made nonparallel. One surface may be planar; and the other, concave, for example. The geometry can be designed to produce a nearly uniform response over a predetermined band of frequencies and to attenuate strongly the frequencies outside the band (see figure).

The new transducer may make it unnecessary to use signal-processing circuits to compensate for the transducer frequency response or to use auxiliary circuits to modify the frequency spectrum of the voltage applied to the crystal. Such circuits would add to the cost of the transducer system.



The **Frequency Response of a Plano-Concave Transducer** covers a broad range. The steep sides of the response curve show that the transducer cuts off extraneous frequencies cleanly.

This work was done by Richard C. Heyser of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 50 on the TSP Request Card.*
NPO-16590

Correcting for Nonlinearity in a Photodetector

A simple positive-feedback circuit would vary the bias voltage as necessary.

NASA's Jet Propulsion Laboratory, Pasadena, California

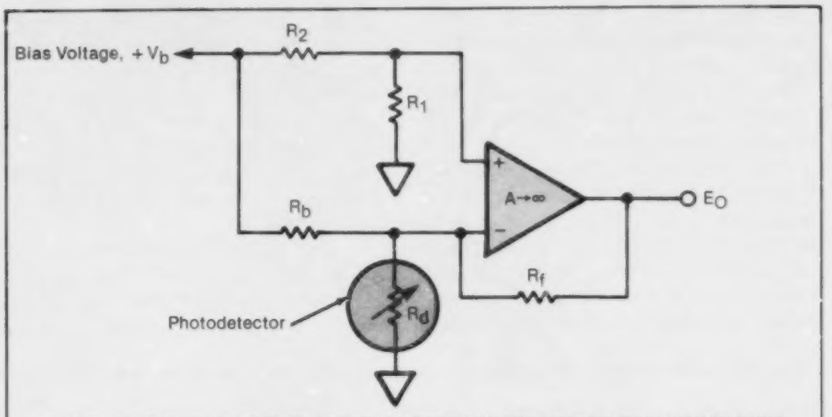
Positive feedback is proposed for compensating for the internal series resistance of a photoconductive detector. The feedback would ensure that the detector-circuit output current varies linearly with the photon flux. The principle can be applied

to linearizing mercury cadmium telluride infrared detectors in Fourier-transform spectrometers and other spectral and imaging instruments.

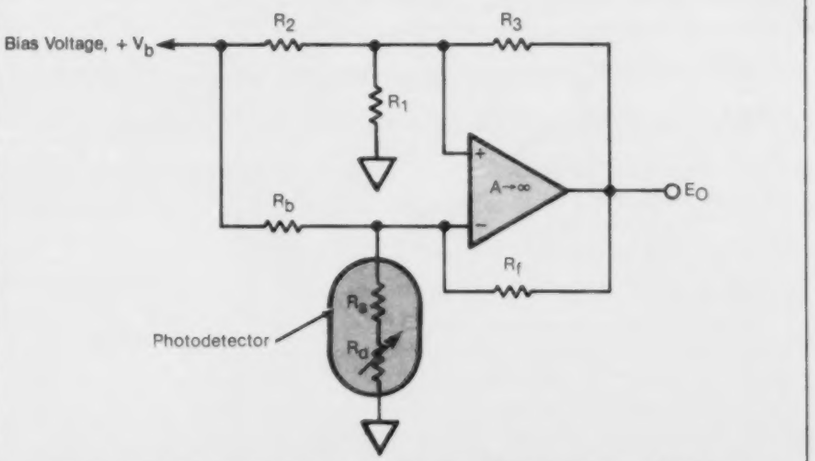
In an ideal photoconductive detector with no internal series resistance, the conductivity is proportional to the incident photon flux. If this ideal detector is biased with a constant voltage, the detector current is proportional to the photon flux plus a constant offset. Such a detector could be connected between an inverting input and ground (see top of figure), and feedback from an operational amplifier through feedback resistor R_f would make the voltage at the inverting input equal to that at the noninverting input. The bias voltage would thus be held constant.

A real photoconductive detector, however, contains an internal series resistance R_s so that the detector conductance no longer varies linearly with the photon flux. Adding a resistor R_3 to the circuit, as shown in the lower half of the figure, allows positive feedback to biasing resistors R_1 and R_2. This feedback increases the detector bias voltage as the flux increases and opposes the effect of R_s. The value of R_3 can be selected so that the positive feedback is just enough to balance out the nonlinear effect of R_s, thereby making the output voltage E_0 vary linearly with the photon flux. This value is given by

$$R_3 = \frac{R_f R_1 R_2}{R_s R_b} \cdot \frac{R_s + R_b}{R_1 + R_2}$$



CIRCUIT FOR IDEAL PHOTODETECTOR (ONE WITH NO SERIES INTERNAL RESISTANCE)



CIRCUIT FOR REAL PHOTODETECTOR (ONE WITH SERIES INTERNAL RESISTANCE)

For an **Ideal Photoconductor,** a simple negative-feedback resistor R_f provides a nearly constant bias voltage on the device. For a **Real Photoconductor,** an additional resistor R_3 provides positive feedback for linearity.

This work was done by Rudolf A. Schindler of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 52 on the TSP Request Card.*
NPO-16055

Improved High/Low Junction Silicon Solar Cell

The air-mass-zero open-circuit voltage is increased to 650 mV.

Lewis Research Center, Cleveland, Ohio

A method has been developed to raise the value of the open-circuit voltage in silicon solar cells by incorporating a high/low junction in the cell emitter.

The power-conversion efficiency of the low-resistivity silicon solar cell is considerably less than the maximum theoretical value mainly because the open-circuit voltage is smaller than simple p/n junction theory predicts. With this method, the air-mass-zero open-circuit voltage has been increased from the 600 mV level to approximately 650 mV.

The figure gives a cross-sectional schematic view of the proposed cell. Shown is the p-type substrate and the n-type emitter comprising a low region and a high-electron-accumulation region. An oxide layer on the illuminated surface contains a high positive charge. Shallow n^+ contact diffusion regions underlie each of the one or more aluminum emitter contacts, and an ohmic contact underlies the p region.

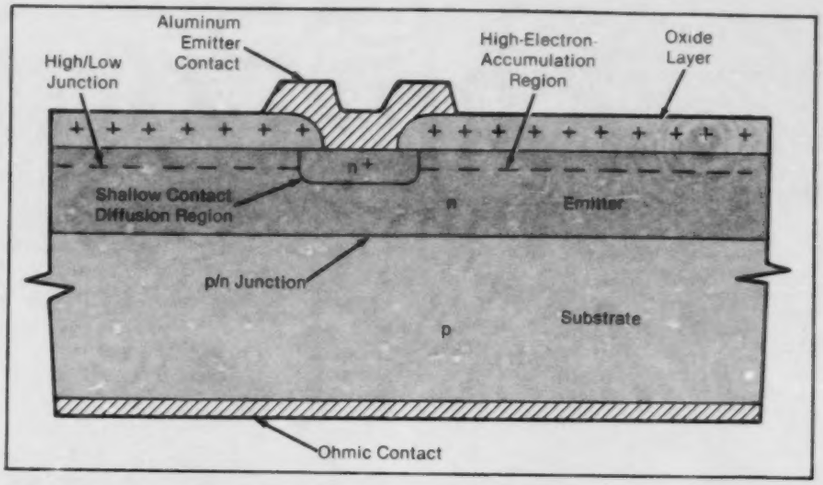
A p/n junction exists between the emitter region and the substrate. A high/low junction has been formed between the

high-electron-accumulation region and the low emitter region. An aluminum metal contact is in ohmic contact with the emitter, and a shallow n^+ diffusion contact is made under this metalized portion of the top surface area. The aluminum emitter contact covers no more than 5 to 10 percent of the surface area.

Provided in the proposed solar cell is a suppression of dark emitter current and an increase of short-circuit current. The emitter is less heavily doped — preferably in the $\sim 10^{18}$ to 10^{19} cm^{-3} range — compared to emitters of conventional cells, which are typically doped to about 10^{20} cm^{-3}. A heavily doped emitter region has the disadvantage that the dark emitter recombination is so large that it limits the maximum open-circuit voltage to about 600 mV. The high/low emitter suppresses the dark emitter recombination current, resulting in power-conversion efficiencies significantly higher than were previously achieved.

This work was done by Arnost Neugroschel, Shing-Chong Pao, Fred A. Lindholm, and Jerry G. Fossum of the University of Florida for **Lewis Research Center.** *For further information, Circle 102 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 29]. Refer to LEW-13618.



In an Oxide-Charge-Induced High/Low Emitter Solar Cell, electron accumulation layer is induced by a positive charge.

A 25-kW Series-Resonant Power Converter

A prototype exhibited an efficiency of 93.9 percent.

Lewis Research Center, Cleveland, Ohio

The feasibility of processing 25 kW of power with a single, transistorized, series-resonant converter stage has been demonstrated by the successful design, development, fabrication, and testing of such a device. This technology was built on the strong technical base of multikilowatt series-resonant converters that have been developed in recent years. This technical base includes advanced switching components, magnetic components, filter components, mathematical circuit models, control philosophies, and switch-drive strategies.

Much of the recent effort had been centered around the application of high-power transistors in resonant converters. Transistor switches display marked advantages over the more commonly applied thyristors. Among these advantages are higher frequency operation, lower switch losses, positive commutation, lower-peak tank currents, and inherent current limiting in the switch. It is anticipated that the eventual application of this technology base to multikilowatt space-power systems will result in both reduced specific mass due to the higher conversion frequencies and in reduced thermal control due to more efficient operation.

To date, the highest-known power level of a resonant power converted designed for space operation was 2.5 kW. However, studies had shown that a module size of 25 kW was appropriate for a multihundred-kilowatt space-power system. As a first step, a 10-kW transistorized dc/dc resonant power converter was designed and tested. As a result of this program, the development of series-resonant converters to the 25-kW power level for spaceborne and airborne applications was successfully accomplished.

A 25-kW resonant dc/dc power converter was designed, developed, fabricated, and tested, using Westinghouse D7ST transistors as the high-power switches. The D7ST transistor was characterized for use as a switch in series-resonant converters, and a refined base-drive circuit was developed.

The converter developed employs four D7ST transistors in a full bridge configuration, operates from a 250- to 350-Vdc input bus, and provides an output power of 25 kW (1,000 V or ± 500 V at 25 Adc). It has a resonant frequency of 20.6 kHz, an output ripple of 3 percent peak-to-peak, regulation of better than 0.1 percent, a response time of less than 2 ms, and its output can be either constant voltage or constant current with automatic crossover. The full-power, 250-V-input electrical efficiency measured was 94.8 percent for the power stage alone, 94.4 percent with housekeeping power included, and 93.9 percent with the losses of the solid-state input circuit breaker and output transient-current limiters included. There are no inherent problems that would prevent this 25-kW design from being upgraded to a space-qualified status.

The developed converter technology provides an efficient, lightweight, high-power converter that can be used by itself or as a module for a higher power (multi-100-kW) system. This technology can also be used as the basis for a high-power, high-frequency (20-kHz), ac power distribution system. In either case, power-system benefits such as lower losses when used for high-voltage distribution, and reduced magnetics and filter mass will be realized.

This work was done by Robert J. Frye of **Lewis Research Center** *and Ronald R. Robson of Hughes Research Laboratories. Further information may be found in NASA CR-168273 [N84-17481/NSP], "25 kW Resonant dc/dc Power Converter" [$14.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14197

Electronic Systems

Hardware, Techniques, and Processes

50 Digital Signal Combining for Conference Calling
52 Fast Initialization of Bubble-Memory Systems
55 Blending Gyro Signals To Improve Control Stability
56 Synchronization of Data Recorded on Different Recorders
58 Wind-Tunnel-Model Leak-Checking System
59 Laser Ranging System
59 Switched-Multibeam Antenna System
62 TV Video-Level Controller

Books & Reports

63 Simulation of PCM Data

Digital Signal Combining for Conference Calling

Signals are combined with minimal noise by use of sums in read-only memories.

John F. Kennedy Space Center, Florida

A digital signal-combining system reduces the number of signal-processing steps by use of read-only memories (ROM's) instead of linear arithmetic operations on the signal amplitudes. Like other digital signal adders, it degrades the signal-to-noise ratio less than do analog adders when a large number of signals is combined. The system is intended especially for combining a number of separate audio signals into one signal for retransmission, as in telephone conference calling.

Figure 1 depicts the operating mode for the simultaneous transmission of telephone signals from subscribers A and B to subscriber C. The audio outputs of the microphones at A and B are processed through analog-to-digital converters, the outputs of which are parallel 8-bit, floating-point numbers representing the instantaneous sampled amplitudes. The parallel bits are converted to serial bit streams for transmission over a long distance to the signal-combining station.

At the combining station the serial bit streams are converted back to parallel. Each 8-bit parallel number provides half of a 16-bit address for a ROM. The ROM is preprogrammed to contain all of the 2^{16} possible sums of the digitized A and B signals. Thus, the ROM acts as an electronic lookup addition table, and its output is a parallel 8-bit floating-point number

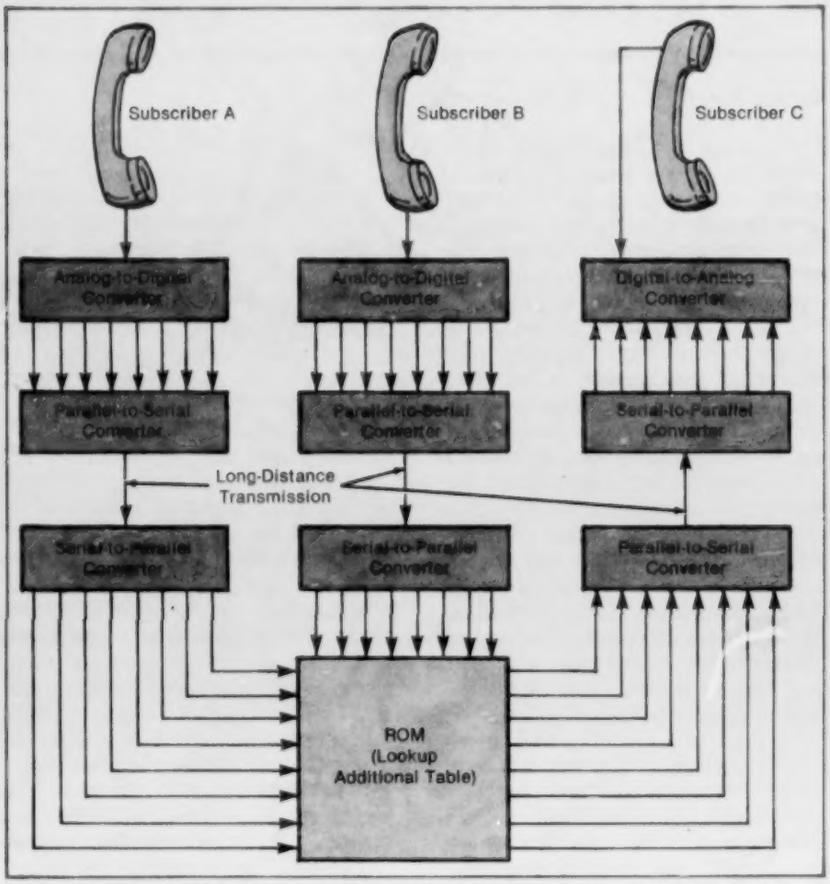
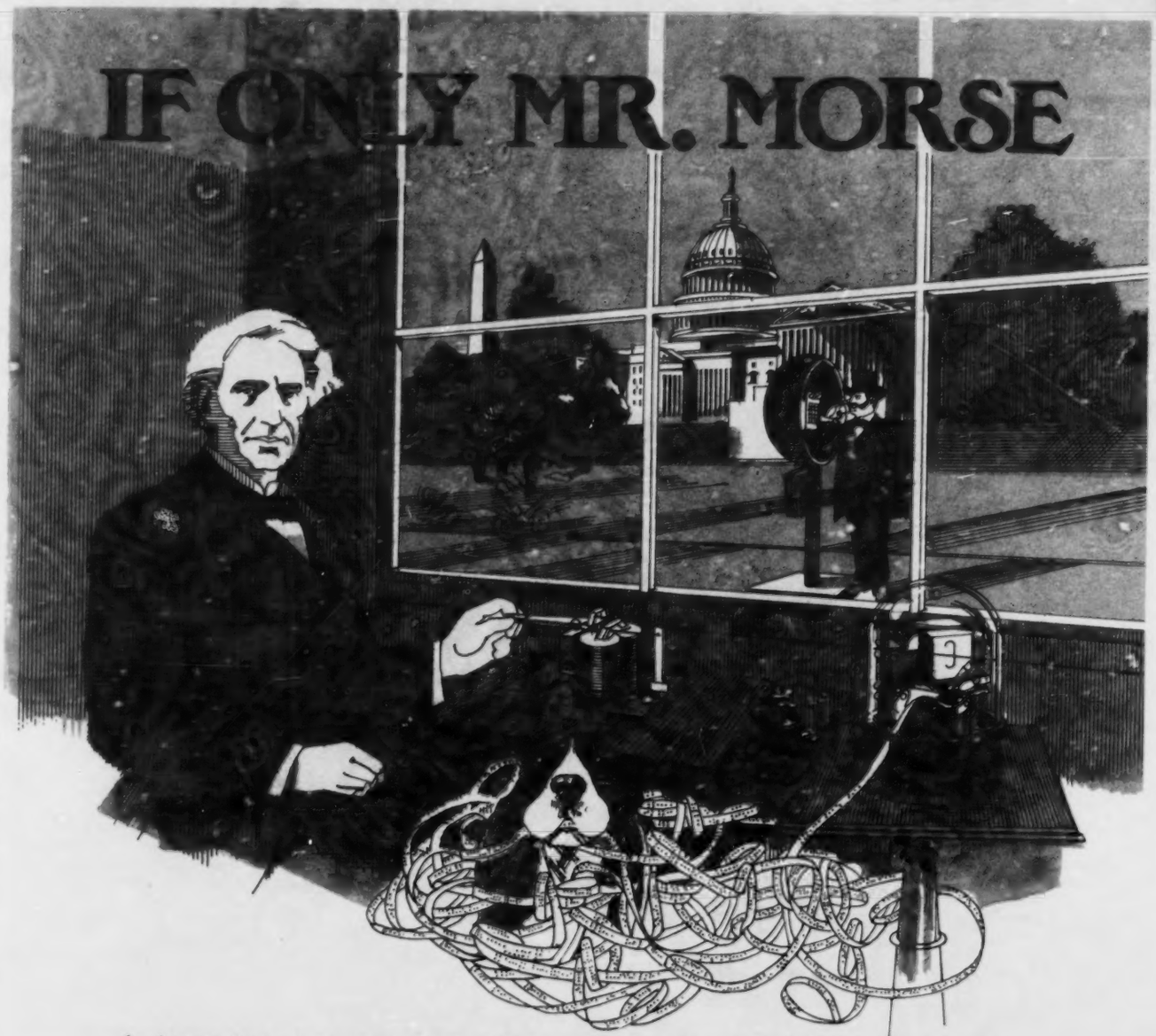


Figure 1. The **Signals From Subscribers A and B** are digitized, transmitted, and combined by addressing a ROM. The combining operation is the electronic equivalent of looking up the value of a function of two variables in a mathematical table. The combined digitized signal is transmitted, converted to analog form, and delivered to subscriber C.

IF ONLY MR. MORSE



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86-2DS

representing the instantaneous sum of the A and B signals.

The ROM output is converted to serial form for long-distance transmission. At the destination, the serial bits are converted to parallel, then to analog form and fed to the receiving headphone of subscriber C.

To increase the number of signals that can be combined, it is necessary to introduce multiple lookup steps or else to make the ROM address wider. Because the number of possible amplitude sums increases exponentially with the address width, an electronic "shortcut" is taken to decrease the size of the required memory: This shortcut is accomplished by elimination of the redundancy in positive and negative sums and differences of the same magnitude.

In the two-subscriber case of Figure 1, the ROM is replaced by the system of Figure 2. Inputs A and B are fed to a sign ROM, a sum ROM, and a difference ROM. The sign ROM determines the output-sign bit and whether the remaining seven output bits represent a sum or a difference. The sign ROM then enables the sum or the difference ROM, whichever is appropriate. The output-sign bit is combined with the seven output bits of the sum or difference ROM into the parallel 8-bit ROM output signal.

To compensate for volume differences among transmitting subscribers, the combining-ROM subsystem can be preceded by a multiplying-ROM subsystem in each subscriber line. In an operation similar to that of the combiner, the multiplier inputs are the seven magnitude bits of the audio signal (the sign bit is not changed) and the six bits of the volume-adjusting multiplication factor. Together, these two inputs provide 13 address bits for the multiplier lookup table, and the multiplier-ROM output comprises the 7 bits of the adjusted signal magnitude.

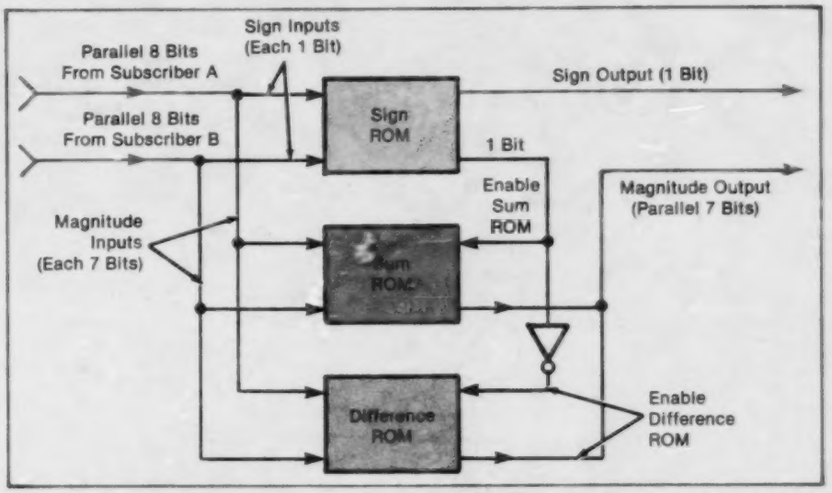


Figure 2. **Sign, Sum, and Difference ROM's** reduce the memory requirement of the ROM of Figure 1 by eliminating redundancy in the "lookup table".

This work was done by Frank Byrne of **Kennedy Space Center.** *For further information, Circle 2 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11285.

Fast Initialization of Bubble-Memory Systems

The improved scheme is several orders of magnitude faster than the normal initialization scheme.

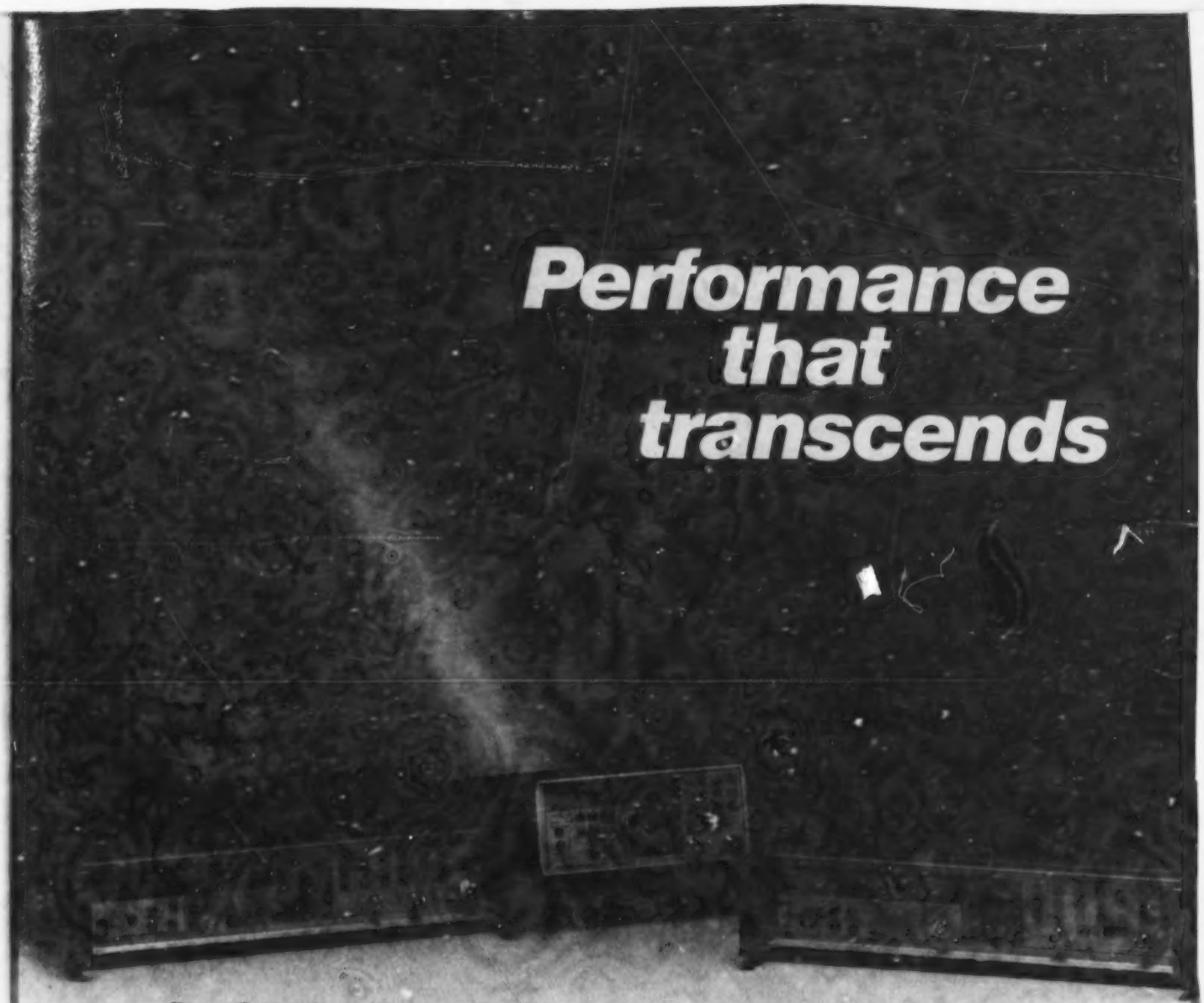
Langley Research Center, Hampton, Virginia

Bubble-memory systems are quickly becoming preferred in environments where nonvolatile storage mediums are required. The implementation of large bubble-memory systems in spacecraft applications requires that the memory modules be power-strobed for the conservation of the available energy resources. Each time a module is turned on for use, it must be initialized to code the redundant loop information of the selected bubble devices into the bubble controller. Present structures of bubble systems dictate that a faster initialization procedure is needed to capitalize on the advantages offered by a bubble-memory system.

EPROM (electrically-programable read-only memory) was chosen as the simplest method to demonstrate the viability of this fast initialization technique. A state-of-the-art commercial bubble-memory device was used. A hardware interface was designed to connect the controlling microprocessor to the bubble-memory circuitry. System software was written to exercise the various functions of the bubble-memory system. A comparison was made between the normal and fast techniques. Future implementations of this approach will utilize the E^2PROM (electrically-erasable programable read-only memory) to provide greater system flexibility.

The figure shows the flow charts for the normal and fast initialization procedures. Both initialization procedures require a system reset (ABORT) before the command is sent to the controller. When the system is initialized normally, the bubble-memory controller (BMC) reads the entire bootloop, decodes it, transfers it to the bootloop register in the format/sense amplifier (FSA), and places the bubble at page zero. This process could take up to 160 ms since there could be two rotations of the minor loops to find and read the bootloop code.

Alternatively, the fast initialization procedure uses system software to load the bootloop information from an external memory into the bootloop register of the FSA. The first different step in the fast initialization process is to issue the PURGE command to clear the controller registers. Next, the parametric register data must be loaded with the same data as those required for the normal initialization. Upon the completion of this, the bootloop register must be loaded from the external memory to the bootloop register in the FSA, accomplished by using the WRITE BOOTLOOP REGISTER



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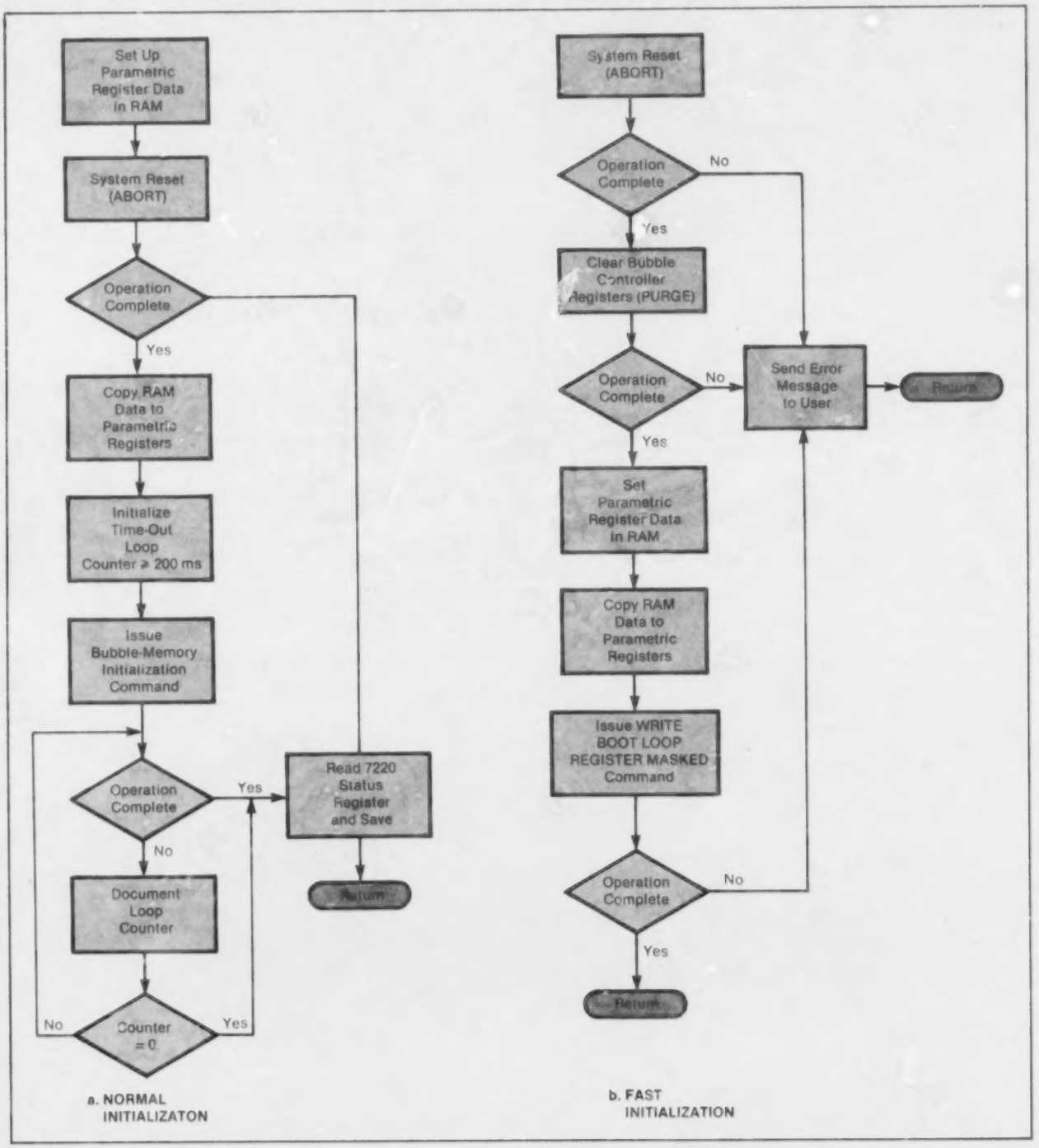


The **Normal and Fast Initialization Techniques** are represented by these flow charts. The fast technique uses a small amount of external storage to load the controller registers at high speed.

MASKED command.

A calculation of the normal initialization time was made from the time the command was issued to the BMC to the time that an "operation complete" status was received in the status register. This time was 117.84 ms. A calculation of the fast initialization time began with the issuance of the PURGE command and ended with the receipt of an "operation complete" in the BMC status register after the completion of the WRITE BOOTLOOP REGISTER MASKED command. This time was only 641 μs. The results of this experiment show that the fast-initialization concept provides several-orders-of-magnitude improvement over the normal initialization scheme. The fast-initialization technique is conceptually applicable to all bubble-memory devices and to systems having higher densities than that of the one used in this investigation.

This work was done by Karen T. Looney, Charles D. Nichols, and Paul J. Hayes of **Langley Research Center.** *Further information may be found in NASA TM-85832 [N84-27977/NSP], "Investigation of Fast Initialization of Spacecraft Bubble Memory Systems" [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

LAR-13357

Blending Gyro Signals To Improve Control Stability

Interference by structural vibrations is reduced by adding the signals from spatially separated gyros.

Lyndon B. Johnson Space Center, Houston, Texas

A signal-processing concept can suppress vibration-induced noise in attitude-control systems. The proposed technique involves blending signals from rate gyroscopes located at different parts of the structure to obtain a composite signal that more nearly represents the rotation of the entire structure. The most likely applications of the concept would be flight-control systems for aircraft.

To apply the technique, it is necessary to have prior knowledge of the vibrational modes of the structure — particularly the dominant modes that contribute to instability in the feedback-control system. As an example, a system that senses the pitch of an airplane must contend with structural vibrations of the fuselage (see figure). The local rate of change of bending slope contributes to the rotation sensed by a rate gyro.

To eliminate the vibrational component from the composite rate-gyro signal, the two pitch-rate gyros are placed forward and aft of the antinode of the dominant vibrational mode, in positions of opposite bending slope for that mode. The forward and aft gyro signals are proportional to

$$\dot{\theta}_F = \dot{\theta}_R + \sum_{i=1}^{n} \sigma_{iF}\,\dot{\eta}_i$$

and

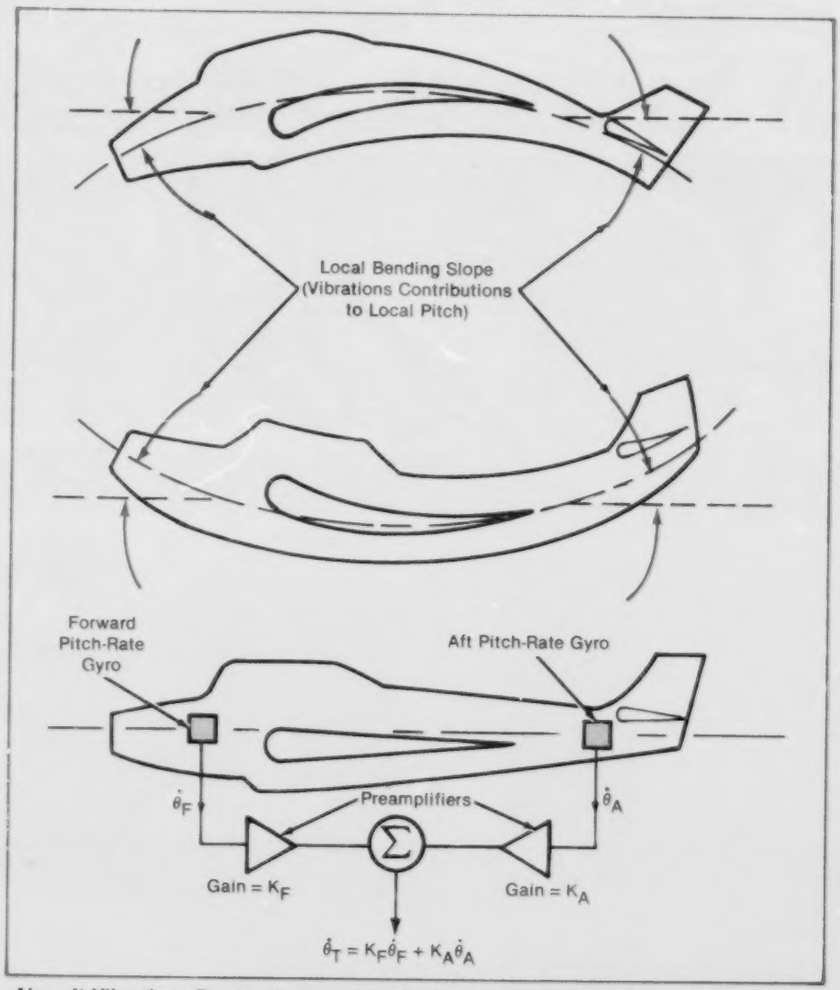
$$\dot{\theta}_A = \dot{\theta}_R + \sum_{i=1}^{n} \sigma_{iA}\dot{\eta}_i$$

respectively, where $\dot{\theta}_F$ and $\dot{\theta}_A$ are the pitch rates sensed by the forward and aft gyros, respectively; $\dot{\theta}_R$ is the rigid-body pitch rate (the pitch rate that would be sensed if there were no vibrations); σ_{iF} and σ_{iA} are bending-slope coefficients for the ith mode; η_i is a generalized amplitude coordinate for the ith mode such that the bending slope at the forward and aft rate-gyro locations is given by $\sigma_{iF}\eta_i$ and $\sigma_{iA}\eta_i$, respectively; and n is the number of bending (vibrational) modes.

As shown schematically at the bottom of the figure, the two gyro signals are summed in such a way that the rigid-body-rotation signal $\dot{\theta}_R$ is not affected while the dominant vibrational-mode signal is suppressed. In principle, the dominant-mode contribution is entirely eliminated by choosing the gains of the summing preamplifiers according to

$$K_F = \frac{-\sigma_{dA}}{\sigma_{dF} - \sigma_{dA}} \text{ and } K_A = \frac{\sigma_{dF}}{\sigma_{dF} - \sigma_{dA}}$$

where the subscript d refers to the dominant mode. With this choice, composite signal $\dot{\theta}_T$ contains only $\dot{\theta}_R$ plus small contributions from minor vibrational modes. This blending technique is superior to band-rejection filtering of the dominant mode in that it has no adverse effect on the processing of rigid-body signal components in the rejection band.



Aircraft Vibrations Perpendicular to the Pitch Axis contribute to the rotations sensed by the pitch-rate gyros. Proper blending of the signals from the gyros can suppress the contribution of the dominant vibrational mode.

This work was done by John F. L. Lee of Honeywell, Inc., for **Johnson Space Center.** *For further information, Circle 64 on the TSP Request Card.*
MSC-20370

Synchronization of Data Recorded on Different Recorders

Electrical and mechanical timing errors would be corrected.

NASA's Jet Propulsion Laboratory, Pasadena, California

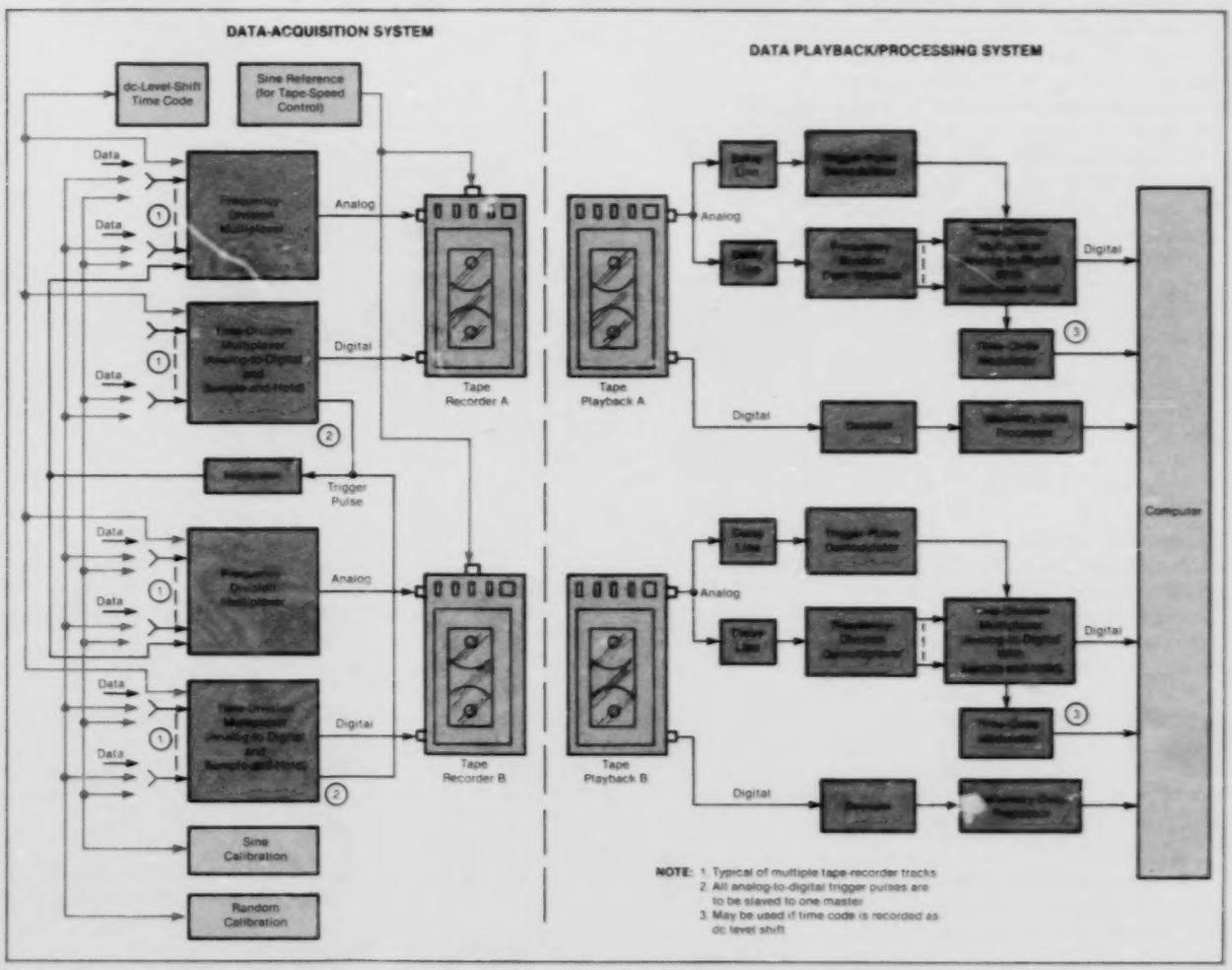
A conceptual electronic timing system would enable the time correlation of analog and digital signals recorded on different magnetic tapes or on different tracks of the same tape. The concept was proposed to improve the analysis of Space Shuttle flight-data tapes containing signals with frequency components up to 50 Hz, but can be used for higher frequencies, possibly in the kilohertz region. It may be useful in other applications requiring the synchronization of data on different data tracks.

The figure shows a simplified block diagram of the concept. The concept involves the recording of timing signals on the data tracks. Four types of timing signal are used (though not all at the same time on the same track):

- A sinusoidal speed reference is recorded on each tape simultaneously with the data and operates through a servo-control system to maintain the same tape speed during playback as during recording;
- The first few minutes of each data channel is occupied by calibration signals consisting of some 50-Hz sinusoid plus some white-noise signal that resolves the integral-cycle phase ambiguity of the sinusoid;
- A train of master trigger pulses is placed simultaneously on all analog data tracks to control the timing of the analog-to-digital converter of each track during playback and laboratory analysis; and
- A dc-level-shift time code is recorded on each analog data track to update the counting of pulses and periods of the reference sinusoid.

The system would correct both electrical and mechanical timing errors and frequency-dependent phase errors. All phase and time errors would be measured in the laboratory when the data tapes are played back. The calibration data would be used to correct the frequency-response and phase errors during the digitization process. Analog phase errors that are independent of frequency could be corrected by delay lines in the playback system or by the signal-analyzing computer after digitization.

This work was done by James H. Wise and James W. McGregor of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 59 on the TSP Request Card.*
NPO-16555



Timing Signals Are Recorded Simultaneously on different magnetic-tape tracks along with data signals to enable the subsequent time correlation of the data.

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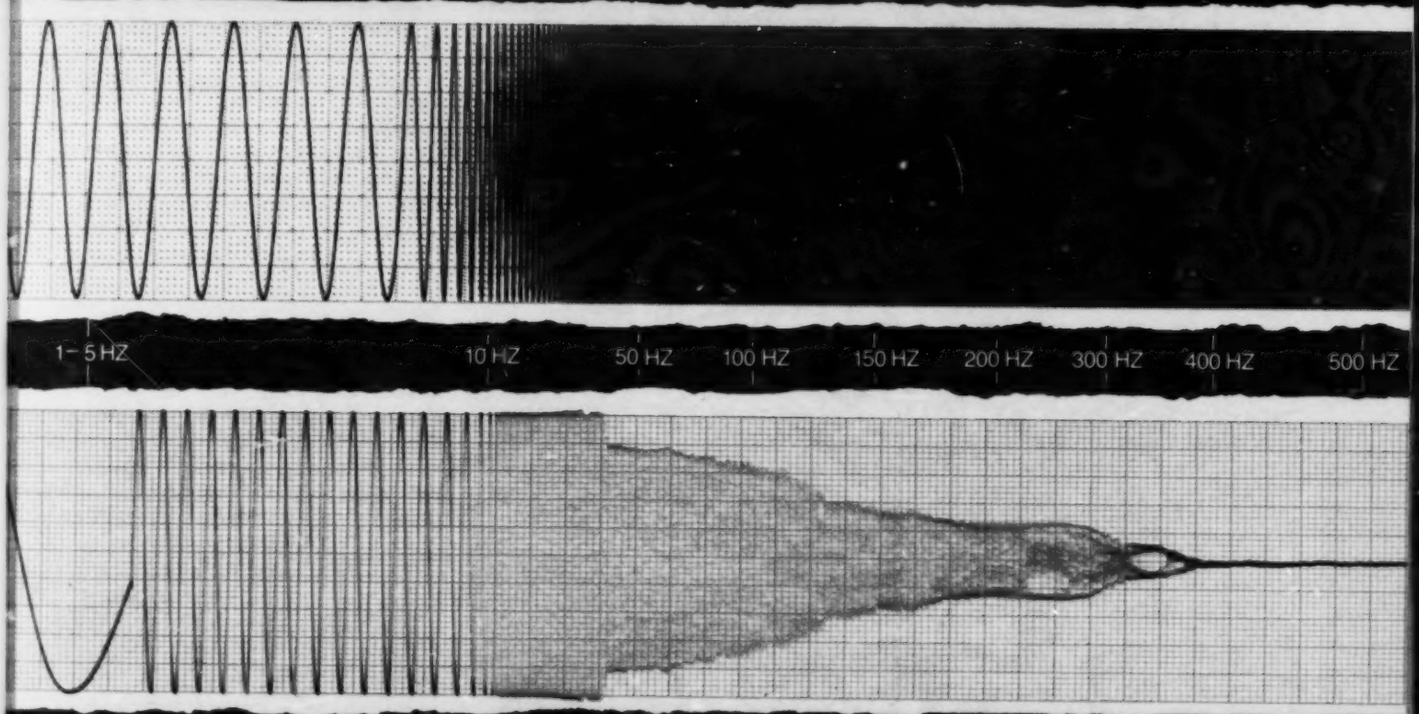

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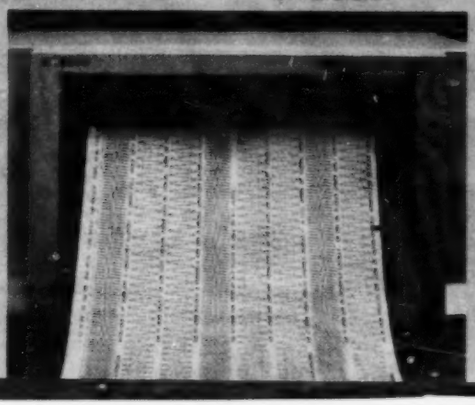

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Circle Reader Action No. 424

Wind-Tunnel-Model Leak-Checking System

A voice-actuated system allows one operator to do the work of three.

Langley Research Center, Hampton, Virginia

A voice-actuated wind-tunnel-model leak-checking system uses a voice-recognition-and-response unit and a graphics terminal to interact with the technician and to provide the technician with visual feedback, respectively (see figure). The computer-based Leakcheck system allows the computer to do more of the total work in checking a model for leaks to reduce the time and manpower required to perform this task.

Conventional methods for checking leaks usually require three people. One technician applies pressure to the orifice selected by a second technician via a control panel in the control room, while the third technician, who generally handles the intercommunication and recordkeeping, requests a decision on the leak rate from the control-room technician, who can see the pressure displayed on a cathode-ray tube (CRT). These steps are repeated until all the orifices on the model have been checked.

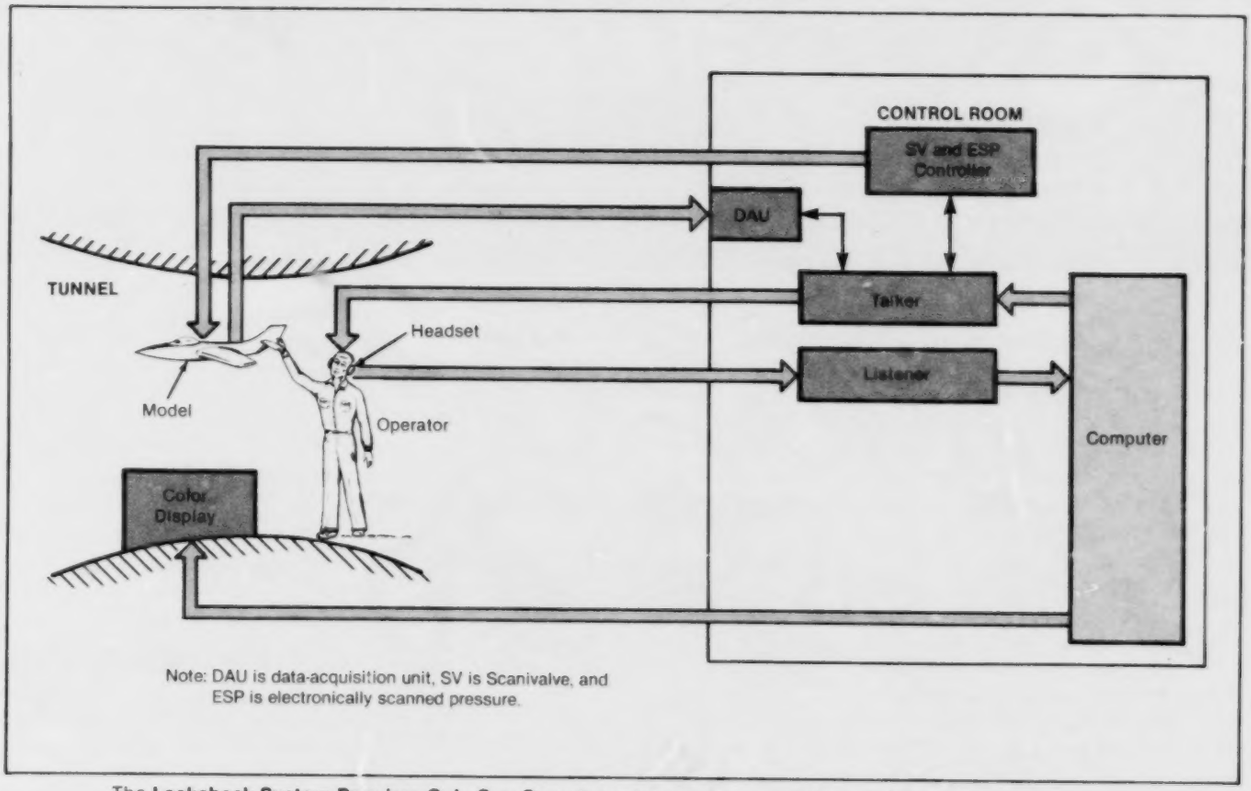
A voice-recognition system, chosen for Leakcheck to free the operator's hands to work on the model, needs only one operator. The system recognizes and responds to the operator's spoken instructions. The recognizer is a speaker-dependent, isolated command unit that can handle a vocabulary of up to 100 separate commands. A spoken command can be a single word or a phrase not longer than 1.5 seconds.

The voice-response unit is a speech synthesizer that can speak any number of words. It uses an algorithm that converts English text strings to speech. With these recognition and response capabilities, the technician can say commands to the computer and hear a positive spoken-word response. A CRT that displays information about the orifice being checked is included in the system to provide the technician with some visual feedback in the leak-checking process.

The only pieces of equipment brought into the tunnel test section are the CRT and the technician's headset. The technician says the name of the desired orifice, or the computer searches automatically for applied pressure. The computer decides whether the leak rate is acceptable, then speaks out the leak status or displays it on the CRT. The computer maintains a data base of status and provides reports. With this arrangement, one technician can perform the entire task, reducing the number of man-hours previously required by a factor of 3.

The Leakcheck system has been installed and tested successfully at the 16-foot (4.9-meter) transonic tunnel at Langley Research Center. Current planning calls for the expansion of this technology to include such other measurement devices as thermocouples. The software will also be modified so that the graphic displays will be device-independent.

This work was done by William E. Larson of **Langley Research Center.** *Further information may be found in NASA TM-86359 [N85-17936/NSP], "A Voice-Actuated Wind Tunnel Model Leak Checking System" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LAR-13449



Note: DAU is data-acquisition unit, SV is Scanivalve, and ESP is electronically scanned pressure.

The **Leakcheck System Requires Only One Operator** using a voice-recognition-and-response system.

Laser Ranging System

Laser system points and focuses a TV camera.

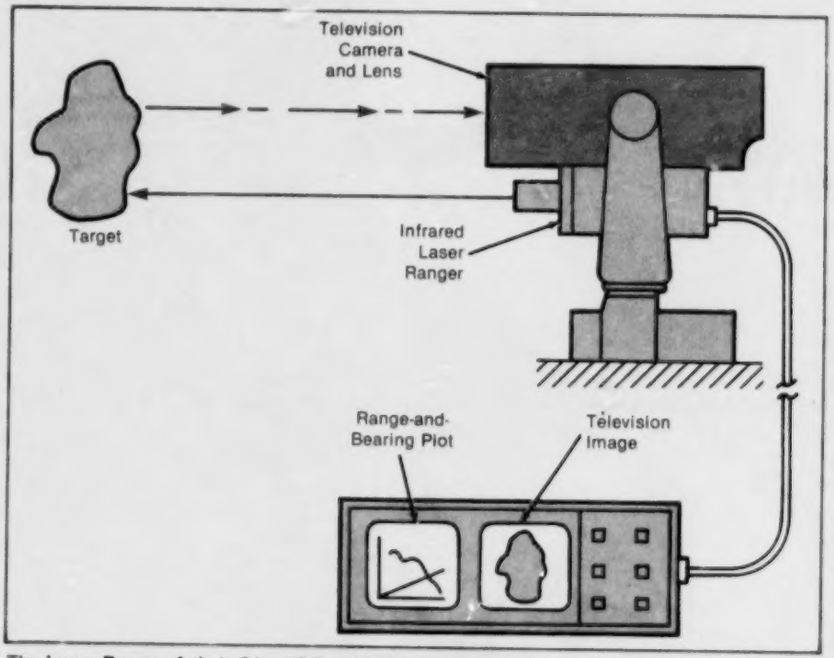
Lyndon B. Johnson Space Center, Houston, Texas

A laser ranger points a closed-circuit television camera at a target object and focuses the camera. The ranger also displays the distance of the object and the rate at which the distance is increasing or decreasing.

The ranger is a modified stock distance-measuring unit mounted on and electrically connected to the television camera (see figure). Effective over a target range of 3 to 500 ft (approximately 1 to 150 m), the ranger was developed for television monitoring of nearby objects from the Space Shuttle. It superimposes the range and the range-rate (speed of approach or recession) data on the television image of the target. The principle can be adapted to such applications as proximity warning and robot control.

A semiconductor laser sends infrared light to the target at 200 pulses per second. Light reflected from the target is focused on a photodiode in the ranger. The range is calculated from the delay between the transmitted pulses and the return-signal photodiode pulses. For greater precision in range, a microprocessor averages the elapsed time for 100 pulses. It also calculates the change between consecutive calculated ranges to determine the range rate.

Additional control circuitry allows the microprocessor to pan, tilt, and focus the camera. In the Space Shuttle application, the system supplants a K_u-band (12 to 18 GHz) radar. Besides freeing the microwave radar for other uses, the laser system reduces the minimum distance-measuring range to far below the 100 ft (30 m) of the radar unit.



The Laser Ranger Axis is 5 in. (12.7 cm) below and parallel to the optical axis of the television camera lens. The ranger transmits pulses at a wavelength of 905 nm.

This work was done by J. Kevin Russell of Lockheed Corp. for **Johnson Space Center.** *For further information, Circle 62 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20870.

Switched-Multibeam Antenna System

Various time delays introduced at intermediate frequency aim the antenna in different directions.

Lyndon B. Johnson Space Center, Houston, Texas

A conceptual multibeam, microwave antenna system can be aimed by various time delays switched at the intermediate frequency (IF) for both transmitted and received signals. The antenna system includes a spherical reflector with a feed horn containing two five-element cross arrays (see Figure 1). Each element in a cross array is connected to a different set of switched delay lines. The antenna should have low and moderate gains and wide coverage.

One of the five-element arrays in the feed horn faces the reflector while the other faces outwardly to serve as a low-gain antenna. The delay network for each element uses energy-efficient electromechanically-latching, double-pole, double-throw (DPDT) switches and relatively low-loss distribution circuitry. By switching different delay lines in and out in each network with various combinations of switch positions, one obtains a total of 256 delay settings or beam directions. The number of beam directions can be doubled by an additional switch, with a loss of only 0.2 dB.

The delay in each time-delay element is independent of frequency. Thus, the transmitted and received beams coincide, even at widely separated frequencies. (This stands in contrast to the more common phase-delay elements, for

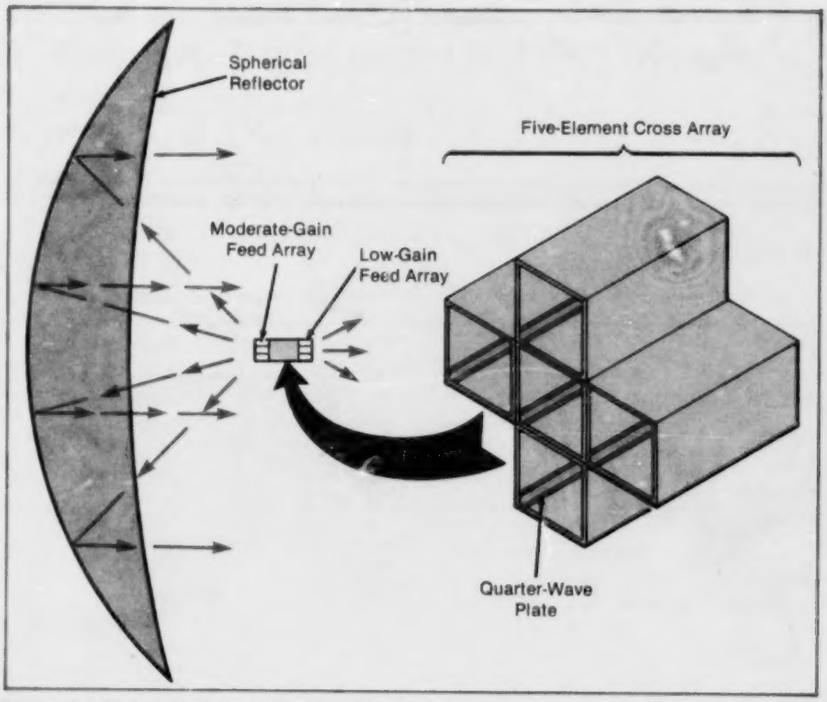


Figure 1. A **Moderate-Gain, Five-Element, Cross-Array Feed Horn** feeds a spherical reflector. A low-gain feed horn faces outwardly.

which the phase varies with frequency.)

Figure 2 shows a distribution and delay-switching network for both transmitted and received signals. If the transmitter beam is also switched at an IF, then up-conversion to the radio frequency is readily done immediately prior to the power-amplification stage.

The antenna feeds are essentially square waveguides with diagonal quarter-wave dielectric plates to generate circular polarizations. Since the transmitter input and the receiver output are orthogonal, there is inherent isolation between them. If additional isolation is desired, the transmitted signal can be attenuated by an abrupt transition to a narrower receiving waveguide having a cutoff frequency above the transmitting frequency.

This work was done by Richard S. Iwasaki of Axiomatix for **Johnson Space Center.** *For further information, Circle 67 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20873.

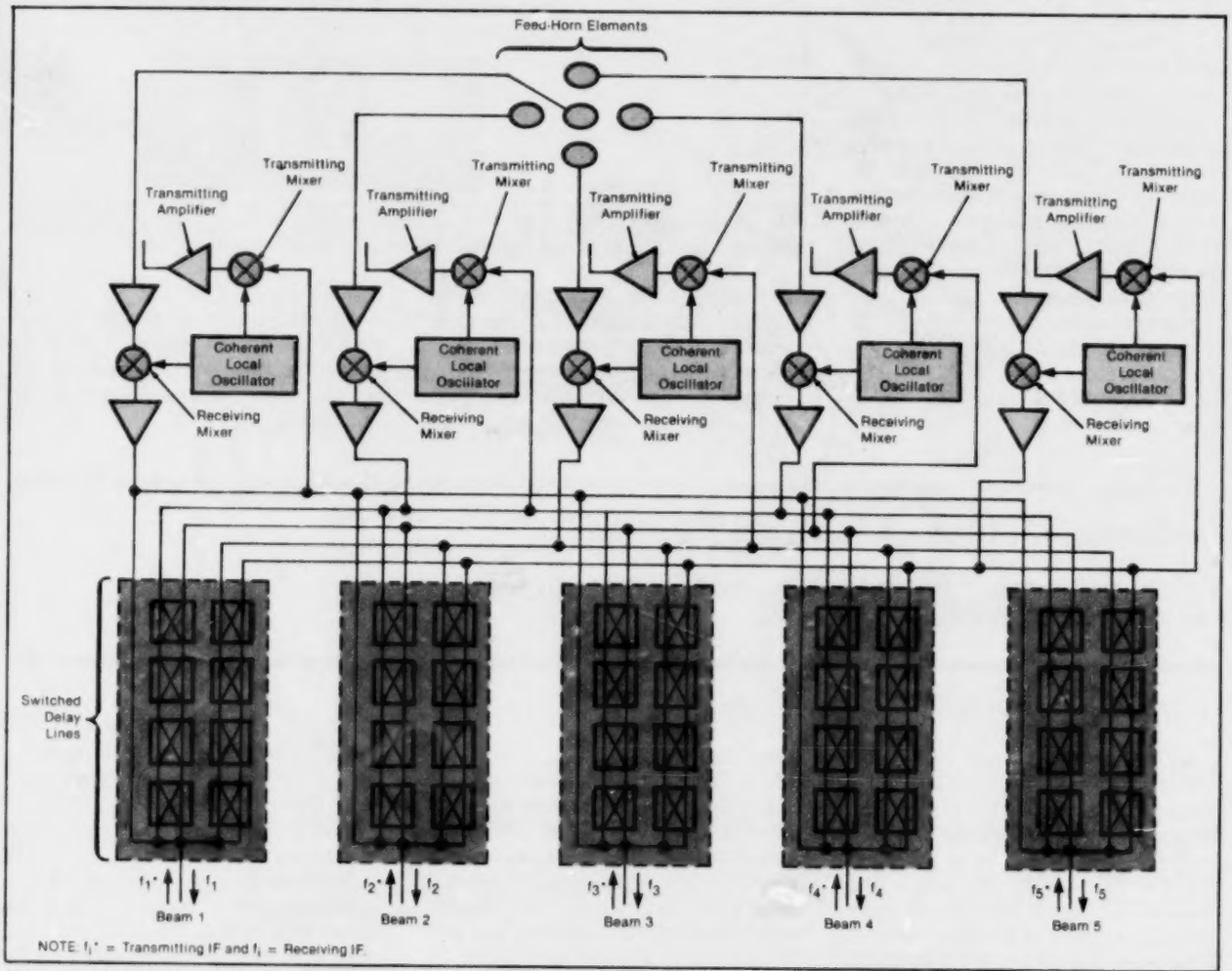


Figure 2. This **Delay-Line Switching Network** aims the antenna by variation of the delay in the feed to each element of the cross-array feed horn of Figure 1.

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TV Video-Level Controller

Constant output is maintained, though luminance varies by 5 million to 1.

Lyndon B. Johnson Space Center, Houston, Texas

With the aid of automatic light control and gain control, a television camera accommodates a maximum light level 5 million times greater than the lowest light level, while outputting a constant 3-V peak signal to processing circuitry. The light-control loop maintains the highlight camera-output current at 330 nA by adjusting the iris opening and the tube voltage. The iris control allows a 50,625-to-1 change of input luminance, and the voltage control allows an additional factor of 20 to 1. Automatic gain control provides an additional 5-to-1 reduction for a net reduction slightly more than 5×10^6 to 1.

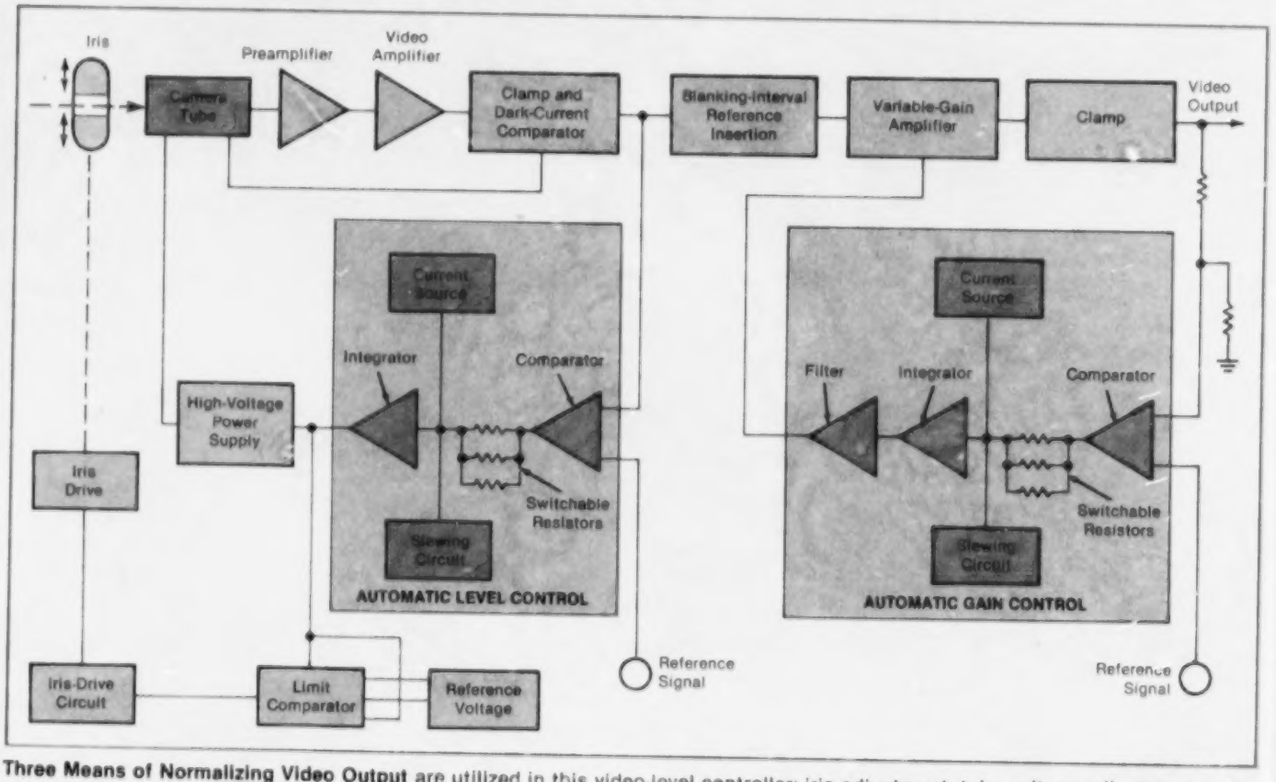
The camera output, after fixed-gain preamplification, is fed to a variable-gain amplifier (see figure), which establishes a dc reference for a clamp and dark-current circuit. The clamped video signal is fed to the automatic-light-control (ALC) loop and, simultaneously, to the automatic-gain-control (AGC) circuit.

In the ALC loop the clamped video is compared with a reference signal, and the comparator output is integrated. The integrator output controls the high-voltage power supply for the tube, which adjusts the camera gain. By switching in the different resistors in the integrator, one selects the fraction (0.005, 0.03, or 0.25) of the scene that exceeds the peak white level and is clipped to peak white in the output.

The integrator output is also fed to a comparator in the iris control loop, which compares the ALC output with a reference level. The comparator output is fed to an iris-drive circuit. Depending on the relationship of the ALC output to the reference, the iris-drive circuit activates a mechanism that increases or decreases the lens opening, thereby increasing or decreasing the amount of light entering the camera.

The AGC loop operates in a manner similar to that of the ALC loop. The video output is compared with a reference signal. The comparator output is fed to an integrator and a filter. As in the ALC circuit, the switchable resistors select the fraction of the scene that is allowed to exceed peak white. The filter output acts to control the gain of a variable-gain amplifier, and hence the video output. Sluing amplifiers in both the ALC and AGC allow rapid response to abrupt changes in light level.

The video-level controller may also be operated manually. In this mode, the lens iris is stationary. An operator manually adjusts the high-voltage power supply. The AGC operates as in the automatic mode. Manual adjustment accommodates a 2,000-to-1 range of light intensity. The high-voltage control allows for a 300-to-1 variation, while the AGC allows for a



Three Means of Normalizing Video Output are utilized in this video-level controller: iris adjustment, tube voltage adjustment, and automatic gain control.

6⅔-to-1 variation.

This work was done by Marvin Kravitz, Larry A. Freedman, Elmer H. Fredd, and Dan E. Denef of RCA Corp. for **Johnson Space Center.** *For further information, Circle 60 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-18578.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Simulation of PCM Data

A program for a communications and control computer simulates pulse-code-modulated data.

Software for simulating pulse-code-modulated (PCM) data from the Space Shuttle during launch preparations was developed for use with the checkout, control, and monitor subsystem (CCMS). The software facilitates testing of the CCMS with the data expected from the main engines, external fuel tanks, operational instrumentation, general-purpose computer, backup flight system, and payload. An understanding of the approach used in this NASA application could benefit designers of other PCM systems.

The table-driven simulator is loaded from disk into a front-end processor of the CCMS, and a menu is written onto the screen of the terminal. Subsequent interaction is through a series of responses to prompts occurring in a logical progression to facilitate easy building, saving, restoration, or execution of the desired simulation. The user's responses govern storage and retrieval of simulation tables, and the disk archives permit rapid format specification without resorting to a lengthy rebuilding process for each use. Simulations on disk are referenced by a six-character alphanumeric label assigned at the time of save-to-disk.

The simulator alternately processes two buffer areas: Data to be transmitted are built in one buffer (by reading through the tables), while the transceiver is transmitting the data from the other buffer.

Visibility into the "health" of the simulator during execution is provided by observing the contents of two memory locations. One location, the health counter, is incremented for each minor frame buffer filled, denoting cycling of the software. The other location, an error counter, increments once for each time the transceiver begins transmitting a buffer before software has completed filling the buffer: It indicates an overrun condition — software unable to keep pace with the transceiver.

The PCM simulator design stresses the ease of use coupled with flexibility. It encompasses all PCM formats necessary for the validation of CCMS software and for hardware/software integration. The simulator program executes in standard CCMS hardware, so no new hardware is required.

This work was done by G.G. Bernstrom of IBM Corp. for **Kennedy Space Center.** *For further information, Circle 45 on the TSP Request Card.*
KSC-11239

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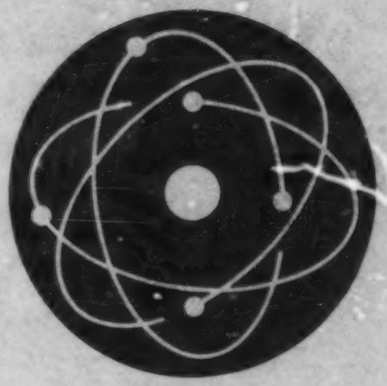
Physical Sciences



Hardware, Techniques, and Processes

64 **Heat-Pipe Array for Large-Area Cooling**
66 **High-Flux Atomic-Oxygen Source**
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Books & Reports

76 **Three-Demensional Radiative-Transfer Equation**

Heat-Pipe Array for Large-Area Cooling

High rates of heat transfer are anticipated.

Lyndon B. Johnson Space Center, Houston, Texas

A prototype evaporative cold plate would gather waste heat from equipment mounted on it. The plate is made by welding together the flanges of several sections of heat pipe (see figure). The heat pipe is a slightly modified version of a type used in heat-rejecting radiator elements.

The heat pipe contains a vapor channel, a liquid channel, and a porous nickel felt wick connecting the channels. The walls of the vapor channel contain 160 circumferential grooves per inch (63 grooves per centimeter). As the heat-transfer liquid evaporates from the grooves, more liquid is drawn up from the liquid channel through the wick.

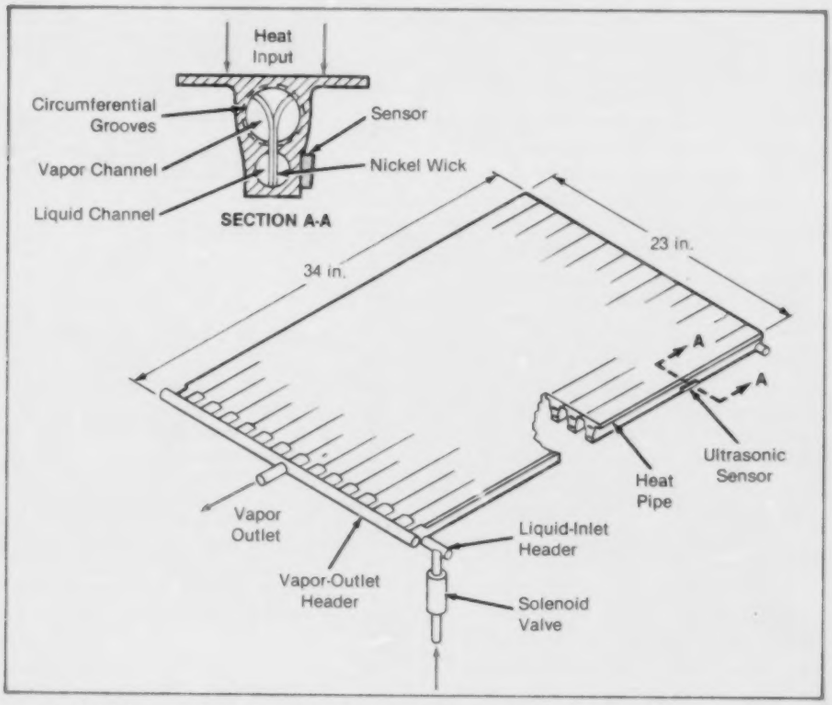
As the liquid depletes, an ultrasonic sensor detects its absence. The sensor signals a solenoid valve to open to fill the liquid channel from a pressurized supply. When the liquid channel is replenished, the sensor signals the valve to close.

Evaporation occurs continuously while the valve cycles on and off. Vapor from the vapor channels in the separate heat pipes is combined into a single outlet header, which directs it to a condenser. The vapor header contains a liquid trap to catch any liquid that is carried into the vapor space. Two liquid headers on each end of the plate assure proper filling and liquid flow to the more-heavily-loaded plate sections.

The plate is expected to transfer heat at high rates by surface evaporation from the many sites in the grooved channels. Heat fluxes in zero gravitation are expected to be 2 W/cm^2 for refrigerant 11 (CCl_3F) and substantially higher for ammonia. Since the plate separates the liquid and vapor phases at the inlet and outlet ports, it eliminates the complexities and uncertainties of two-phase flow in zero gravity. On Earth, the inlet valve enables the plate to operate at relatively-large height differences with other plates in the same system.

This work was done by Fred Edelstein and Richard F. Brown of Grumman Aerospace Corp. for **Johnson Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20946.



The **Cold Plate** consists of sections of heat pipe welded together side-by-side at the flanges.

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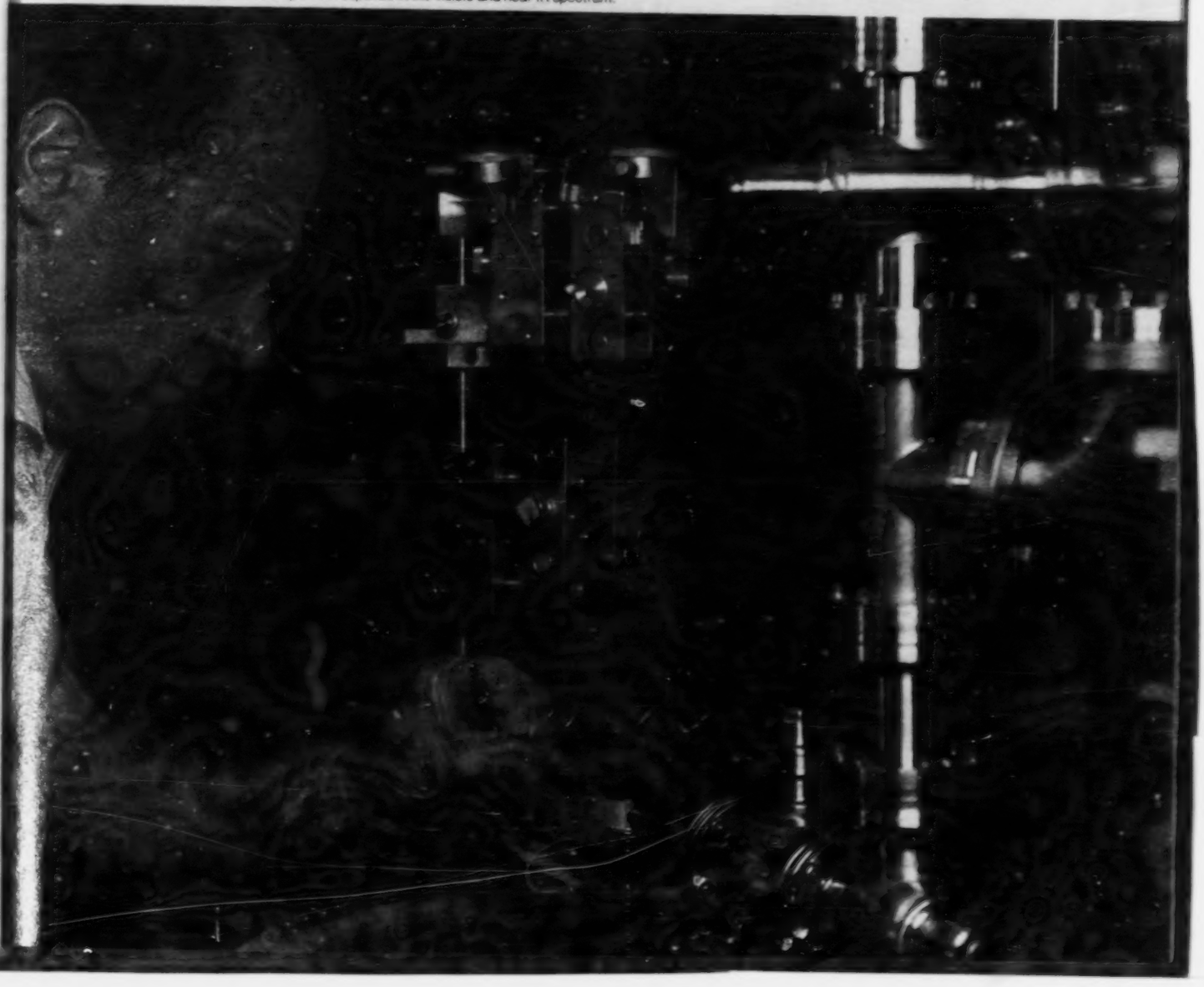


High-Flux Atomic-Oxygen Source

Beams of pure ground-state oxygen atoms would be produced.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed apparatus can generate high fluxes (about 10^{15} atoms/cm^2-s) of ground-state (^{3}P) oxygen atoms. The kinetic energy would be variable in the range of 3 to 10 eV, and the beam would be free of contaminants, such as ions, metastable ^{1}S or ^{1}D oxygen atoms, or other neutral species. Designed specifically to study the degradation of materials and spacecraft glow phenomena in low Earth orbits, this oxygen-atom beam source could be used to study gas-phase collision phenomena involving energetic oxygen atoms.

In the proposed source (see figure), electrons are generated at a heated filament of LaB_6 or W. Bias voltages V_1 and V_2 accelerate the electrons to the proper energy (6.5 eV) to maximize the dissociative attachment of a beam of O_2 gas (that is, the separation of O_2 molecules into O^- ions). A solenoidal magnetic field provided by superconducting coils contains the electrons e and the ions O^- produced in the dissociative-attachment process.

The ions are accelerated to the desired final energy eV_2 and pass through a cavity containing a laser beam where the electrons are photodetached. The laser is tuned to 2.5 eV, which is the photon energy at which the detached neutral atoms are entirely in the ground ^{3}P state. The detachment efficiency is increased by the multiple reflection of the laser beam between two mirrors: Typically 50 to 100 passes are made.

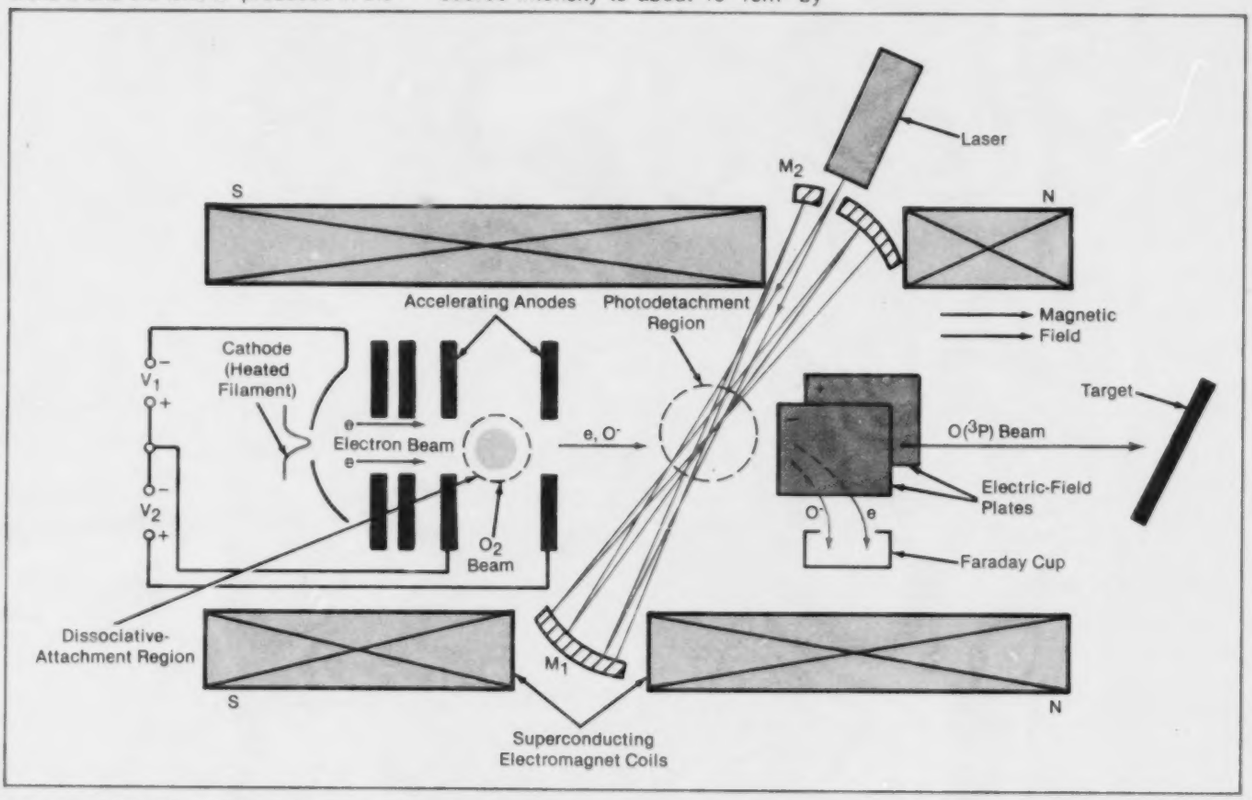
After the detachment, the O(^{3}P) atoms travel toward the surface of the target to be tested. The sample should be placed as closely as possible to the detachment region — to minimize the loss of O(^{3}P) by divergence after detachment. Electrons and undetached O^- ions are deflected by electric-field plates (giving a trochoidal deflection by **E** × **B**) into a collecting Faraday cup.

It should be possible to increase the source intensity to about 10^{17}/cm^2 by scaling of the sizes of the beams from the currently proposed 1 cm diameter to 5 cm diameter. If lower atomic fluxes are desired (up to 10^{13}/cm^2-s), then a lower confining magnetic field is required, and nonsuperconducting windings may be used in the magnet. In this case, the extraction of the O^- ions is possible in the dissociative-attachment region in a direction perpendicular to the magnetic axis.

It should also be possible to use the same scheme to prepare atomic-oxygen beams from a variety of oxygen-containing gases (for example CO, NO, N_2O, and CO_2). The particular gas used determines the energy spread and divergence angle in the O(^{3}P) beam.

This work was done by Ara Chutjian and Otto Orient of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 30 on the TSP Request Card.*

NPO-16640



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Partial-Transmission Scintillation Detector for Ions

Only the outer portion of the ion beam is sampled to prevent unnecessary energy losses.

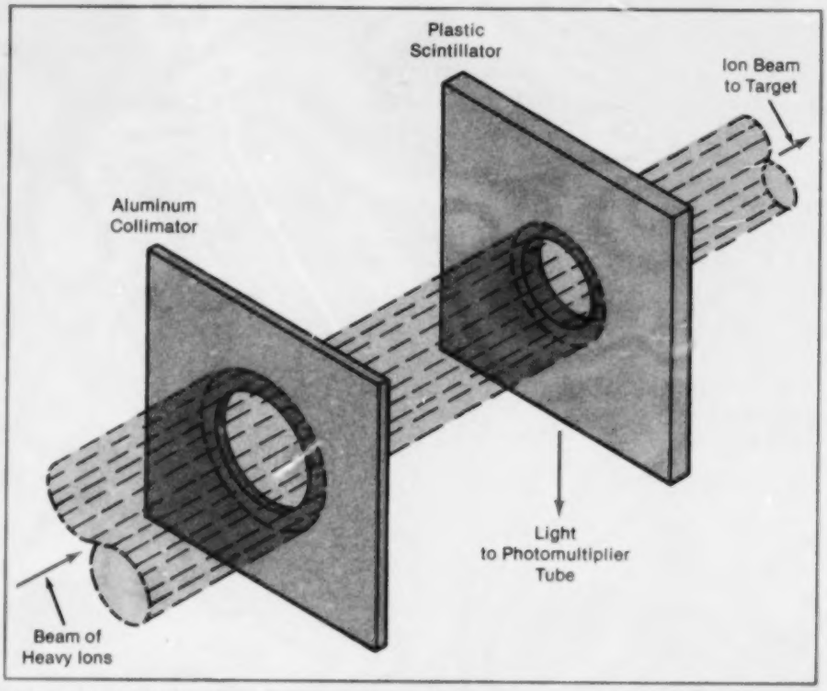
NASA's Jet Propulsion Laboratory, Pasadena, California

The flux of heavy ions in a beam can now be measured without significantly reducing the energies of the ions in the central part of the beam. Previously, the ion flux was measured by passing the beam through a scintillation foil coupled to a photomultiplier tube. The ions lost kinetic energy as they traversed the foil. The use of thin foils (0.5 micrometer or less in thickness) to reduce the energy loss was difficult, however, because the foils were fragile and often could not withstand the handling and vibration.

A new measurement device allows only the periphery of the beam to pass through a scintillation material. The total flux in a uniform beam can be inferred from the peripheral flux. The device thus provides readings without reducing the energy of the ions in the middle of the beam.

The ion beam is collimated by a hole in an aluminum plate (see figure). The beam then passes through a hole in a plastic scintillation plate. This second hole is coaxial with the first one and slightly smaller in diameter. This hole thus intercepts the edge of the beam. The ions impinging on the plastic cause it to scintillate, and the scintillation is measured by a photomultiplier tube.

This work was done by Carl J. Malone and John A. Zoutendyk of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 12 on the TSP Request Card.*
NPO-16501



A Plastic Scintillation Screen measures heavy-ion flux with minimal effect on the middle of the ion beam. The measurement device was developed for ion beams used in studies of how fast, heavy ions affect integrated-circuit chips.

Solid-Sorbent Air Sampler

Portable unit takes eight 24-hour samples.

Lyndon B. Johnson Space Center, Houston, Texas

Volatile organic compounds in air are collected for analysis by a portable, self-contained sampling apparatus. The sampled air is drawn through the sorbent material, a commercial porous polymer of 2,3-diphenyl-p-phenylene oxide. High-boiling-point organic compounds are adsorbed onto the polymer, while low-boiling-point organics, O_2, N_2, Ar, CO_2, CO, and H_2O, pass through and are returned to the atmosphere.

The sampling apparatus (see figure) includes eight glass-lined stainless-steel sample tubes filled with the sorbent. The tubes are normally isolated from each other (to prevent cross-contamination) and from the atmosphere by a manually-operated 18-port switching valve.

As shown schematically at the bottom of the figure, the valve is turned to connect the desired sample tube to the atmosphere, and air is drawn through the tube by a pump. At the end of the sampling period (normally, 24 hours), the operator turns the valve handle to the next position, thereby exposing a new sample while isolating and protecting the

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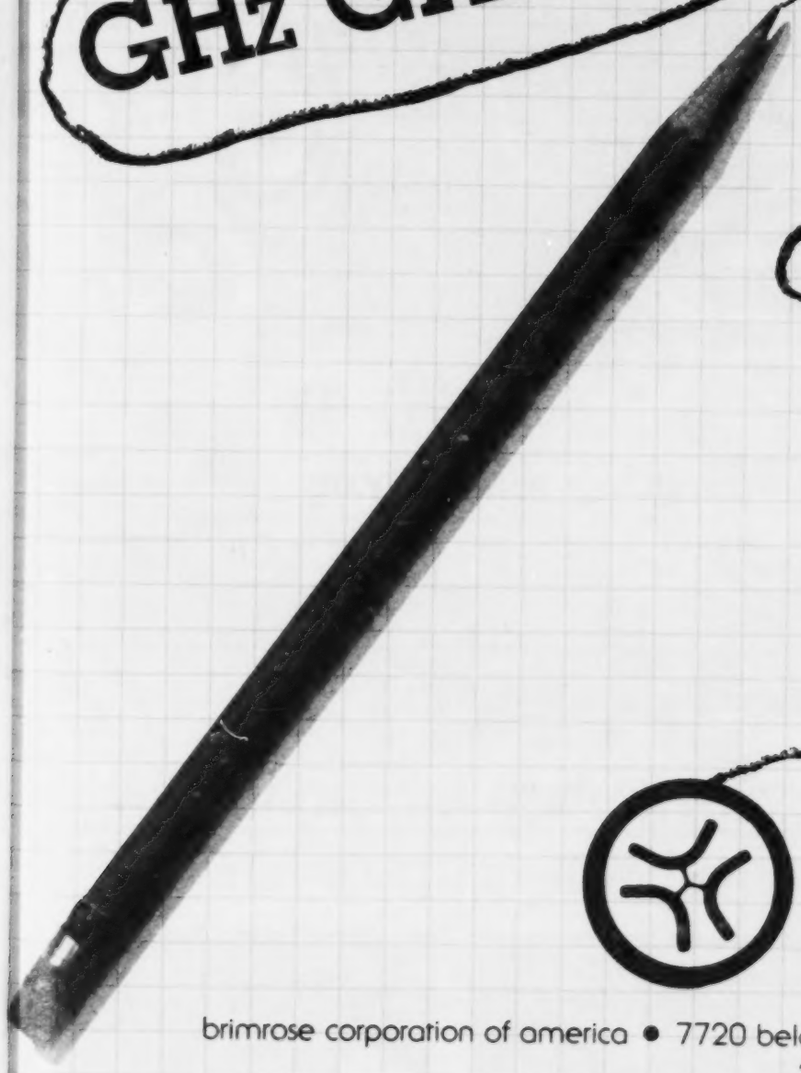

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previous sample(s).

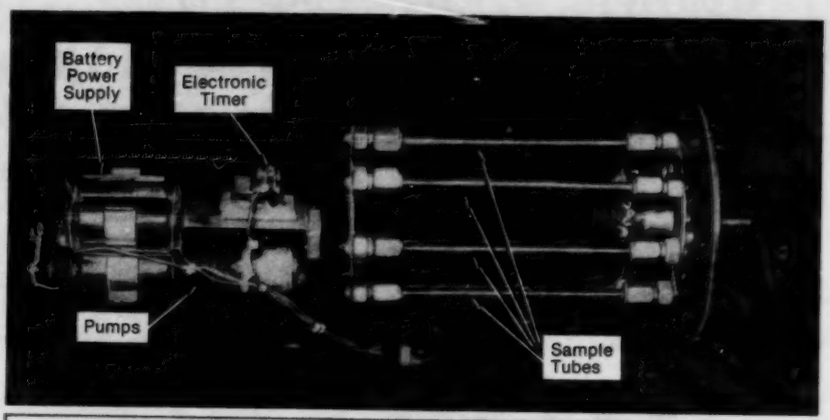
Electrical power for the 1.5-V pump motor is controlled by a 3-V timing circuit, the output of which is adjustable from one pulse every 7 seconds to continuous: This enables the sampling airflow rate to be preset at a value between 0.1 and 0.5 cm^3/min. The motor and timer are both powered by alkaline C-cells, which operate continuously for up to 21 days.

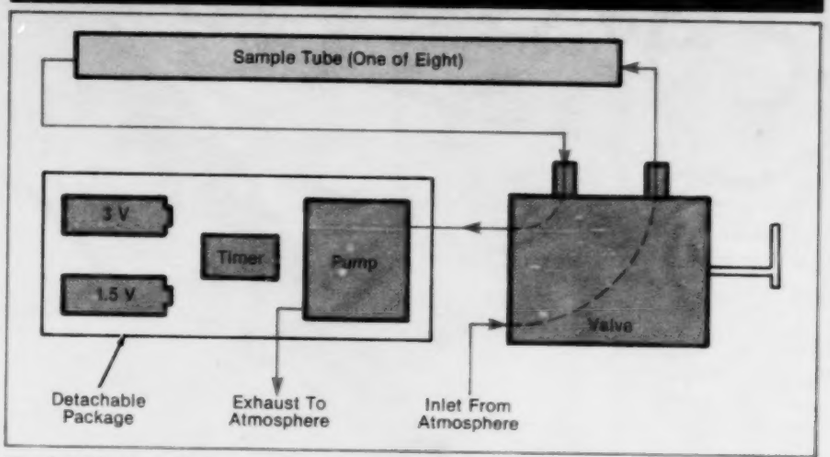
For analysis, the sample tubes remain in place and are connected through the valve to a standard gas-chromatographic/mass-spectrometric system. Since the tubes do not have to be handled or exposed to the atmosphere during analysis, the risk of sample contamination is further reduced.

Although designed for checking air in spacecraft, the sampler is readily adaptable to such other applications as leak detection, gas-mixture analysis, and ambient-air monitoring. The unit is lightweight and compact [3.3 lb (1.5 kg), 4.5 in. (11.4 cm) in outside diameter, and 8 in. (20.3 cm) long]. Operation is simple: Power must be turned on and off, and the valve handle must be turned manually; but no other operator intervention is required.

This work was done by Theodore J. Galen of Northrop Services, Inc., for **Johnson Space Center.** *For further information, Circle 40 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20653.





The **Solid-Sorbent Air Sampler** includes eight sample tubes filled with a polymeric sorbent. Organic compounds in the atmosphere are adsorbed when air is pumped through the sorbent.

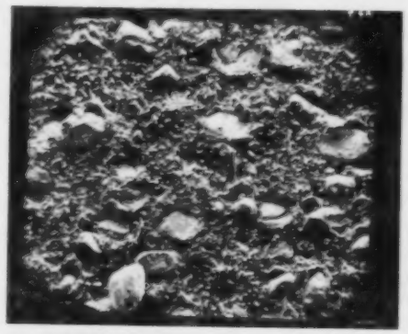
Mapping the Structure of Heterogeneous Materials

An image-processing microdensitometer/Fourier analyzer yields statistics of subcomponent distribution.

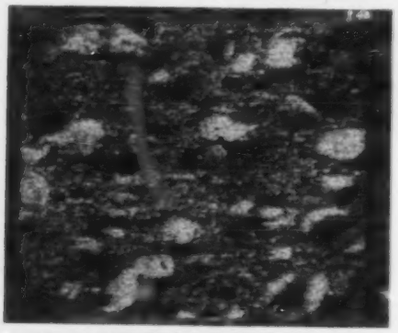
NASA's Jet Propulsion Laboratory, Pasadena, California

A nondestructive method for studying the structure of heterogeneous materials uses energy-dispersive X-ray analysis in a scanning electron microscope. A scanning microdensitometer/Fourier analyzer (SMFA) is applied to the SEM images to obtain statistics about the sample structure.

The method was originally developed for studying the effect on combustion of the fine structure of composite solid propellants. The propellant studied includes ammonium perchlorate as an oxidizer and hydroxyl-terminated polybutadiene as a binder. Three samples were prepared for analysis; one with coarse oxidizer particles (mass mean particle size approximately 200 μm), one with fine particles (10 μm),



SCANNING-ELECTRON-MICROSCOPE PHOTOGRAPH OF A PROPELLANT



ENERGY-DISPERSIVE X-RAY ANALYSIS CHLORINE MAP OF THE PROPELLANT SHOWN AT THE LEFT

Figure 1. **Aspects of the Oxidizer Chlorine Distribution** in a propellant are shown by simple scanning-electron microscopy with energy-dispersive X-ray analysis.

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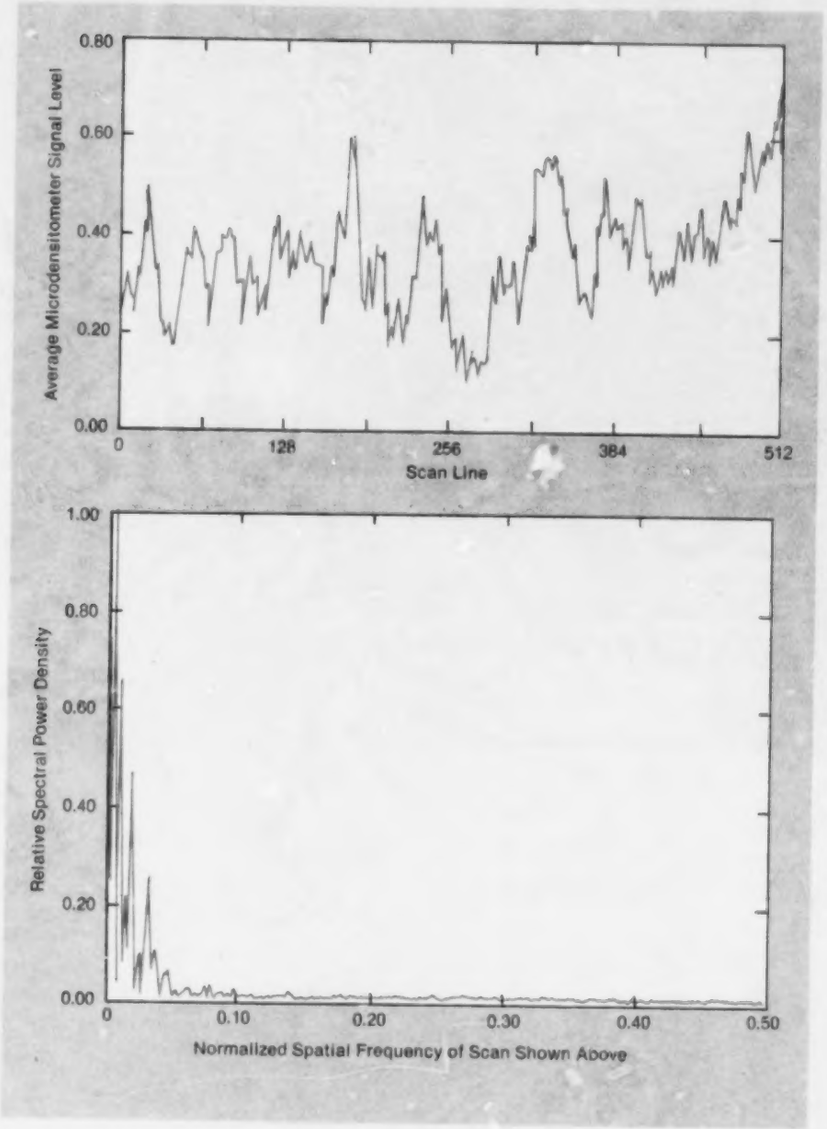

and one containing both size groups. The results for a representative bimodal sample are shown in the figures.

Since there is chlorine in the oxidizer, but not in the binder, its presence maps the oxidizer distribution. The SEM images are analyzed with the SMFA, first to obtain the projection of the chlorine concentration along the axis, and then to obtain the spatial-frequency distribution of the fluctuations in that distribution. Finally, by taking the reciprocals of the frequencies of peaks in the spatial frequency distribution, characteristic dimensions related to the sample are obtained.

From tabulations of the characteristic dimensions for a number of samples, it appears that the characteristic dimensions correspond approximately to the range of particle sizes in the samples. The characteristic dimensions for the coarse samples ranged from 45 to 398 μm; those for the fine samples, from 8 to 381 μm.

This work was done by Leon D. Strand, Norman S. Cohen, and Miguel A. Hernan of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 17 on the TSP Request Card.*
NPO-16487

Figure 2. **Analyses of Scanning-Microdensitometer Measurements** of the chlorine map in Figure 1 yield data that help to characterize the oxidizer-density distribution.

Electro-optical Tuning of Fabry-Perot Interferometers

A compact unit can operate much faster than conventional piezoelectric scanners.

Goddard Space Flight Center, Greenbelt, Maryland

A proposed electro-optical method of tuning or scanning the passband of a Fabry-Perot interferometer can be much faster than previous methods and employ more compact equipment. In a Fabry-Perot interferometer, two parallel glass plates, separated by a few centimeters, are partly silvered on their inner surfaces so that an incoming light beam is repeatedly reflected between them before it is transmitted to instrumentation. Until now, this type of interferometer has been tuned by the adjustment of separation between the plates. This separation could be changed either by a voltage applied to a piezoelectric transducer on one of the mirrors or by a change in pressure of a gas between the mirrors.

Piezoelectric scanners, however, are limited in their tuning speeds. For visible light, a piezoelectric scanner takes about 10 milliseconds per interferometer order, and scanning time is longer for light of longer wavelengths. Moreover, piezoelectric scanners add to the interferometer size and become bulkier when greater scanning range is needed. Pressure scanners are even slower than the piezoelectric models and require gas-handling equipment.

In one version of the proposed scanner, a Pockels cell crystal is placed between the mirrors of the Fabry-Perot interferometer (see figure). Such a cell, usually made of a birefringent material like potassium dihydrogen phosphate, changes its

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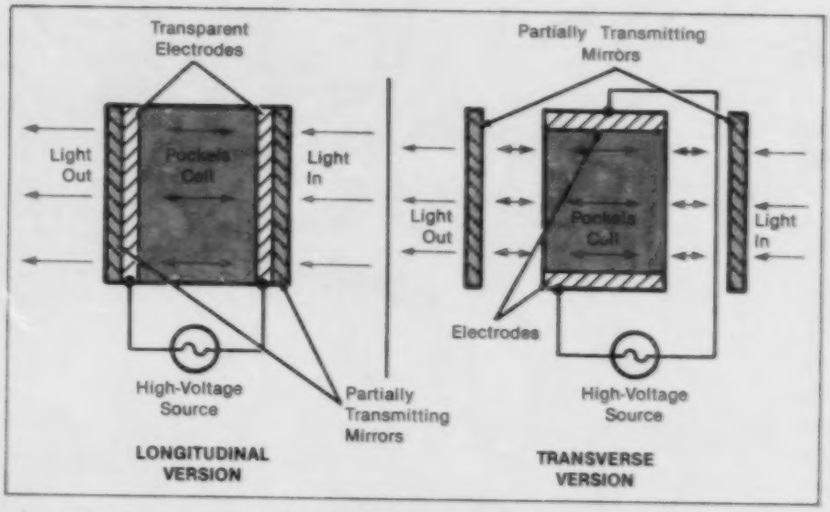
refractive index under an applied electric field. The Pockels crystal is oriented so that one of its electrically induced axes is parallel to the plane of polarization of the incident light beam. A voltage applied across the crystal surfaces changes the optical path length between the mirrors without changing the gap between them. The interferometer therefore can be scanned by changes in voltage on the Pockels cell.

The voltage is applied through electrodes on opposite faces of the cell. The mirrors may be affixed directly to the cell faces. If a longitudinal electric field is used and the electrodes are not only conductive but also transparent to the incident light, these electrodes can be deposited as films over the entire end faces of the crystal. (Indium tin oxide, for example, is conductive and is transparent at visible wavelengths.) The electrodes would then create a highly-uniform electric field within the crystal, and the Pockels cell could be made very thin. Reflective film could be deposited directly on the electrodes, and the entire interferometer would be compact.

The new electro-optic scanner would scan a given range in one-millionth the time of a piezoelectric scanner — tens to hundreds of nanoseconds per interferometer order. At the same time, its small size would reduce the size of an interferometer.



A **High Voltage** creates an electric field in a Pockels cell, changing its refractive properties. The cell therefore changes the optical path length between the mirrors without mechanically moving anything in the gap. The high voltage can be varied rapidly to scan the interferometer. The voltage is applied longitudinally or transversely, depending on the type of Pockels cell.

This work was done by Geary K. Schwemmer of **Goddard Space Flight Center.** *For further information, Circle 73 on the TSP Request Card. GSC-12971*

Recording Interferograms Holographically

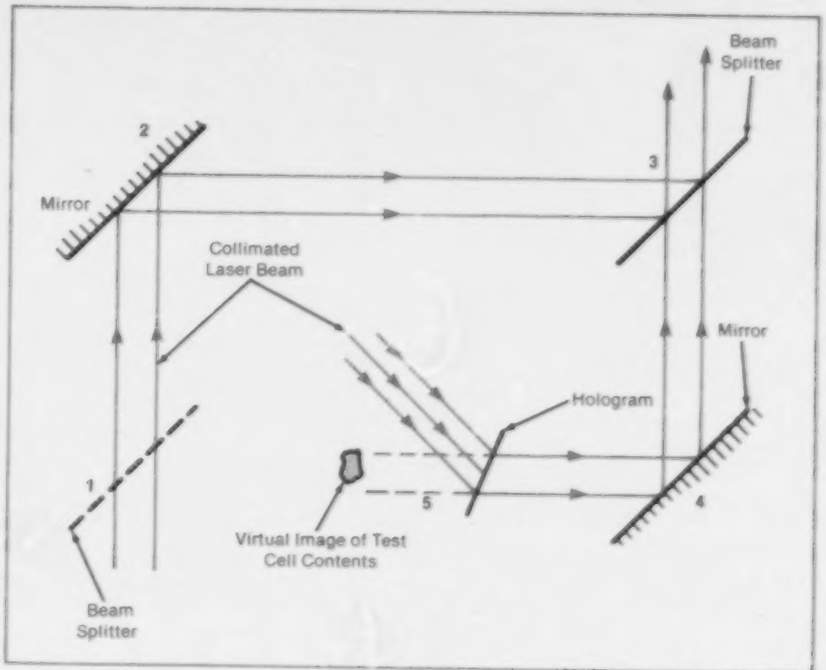
Images of experiments are stored for later analysis.

Marshall Space Flight Center, Alabama

A holographic system reconstructs interferometer images recorded during experiments for later, more detailed analysis. The system was developed for experiments on crystal growth during space flights. With it, images are recorded rapidly under the constraints of the experiments and are later examined on the ground.

The holographic images are reconstructed in a modified Mach-Zehnder interferometer, an instrument often used to measure the spatial variation of the index of refraction of a gas. In its classical form, the Mach-Zehnder interferometer consists of two beam splitters (semitransparent mirrors) and two wholly reflecting mirrors at alternate corners of a rectangle. Halves of an incoming light beam travel along opposite faces of the rectangle. The halves combine at a semitransparent mirror to form an interference pattern.

The classical interferometer was modified for holography by removing the en-



In a **Classical Mach-Zehnder Interferometer,** path 1-2-3 is the reference leg, and path 1-4-3 is the object leg. In the interferometer modified for holography, the beam splitter at 1 is removed, as indicated by the dotted line, and path 1-2-3 is still the reference leg, but path 5-4-3 is now the object leg.

trance semireflecting mirror and inserting the holographic recording in one of the legs (see figure). A collimated laser beam is projected through the hologram and directed to the remaining semitransparent mirror. There it combines with a reference beam from the same laser to form a virtual image of the original experiment.

This work was done by Ellis R. Comeens and Robert L. Kurtz of TAI Corp. for **Marshall Space Flight Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-26024.

Comparative Thermal-Conductivity Test Technique

Approximate thermal conductivities are determined rapidly.

Lyndon B. Johnson Space Center, Houston, Texas

The thermal conductivity of a material can be estimated conveniently in a test procedure that compares it to a material of known conductivity. This procedure can be used to rate quickly the candidate materials for applications in which thermal conductivity is a prime consideration. Once the selection has been reduced to one or two candidates, formal thermal-conductivity test methods can be used to verify the results of the inexpensive comparative technique.

An exploded view of the test arrangement is shown in the figure. The two 1- by 6-in. (2.5- by 15-cm) test specimens, one of known thermal conductivity, are well separated by insulation and then wrapped in insulation. This assembly is then partially inserted into a tube furnace so that one end of each specimen is exposed to the furnace temperature, and the other end is open to the atmosphere. Thermocouples are attached to both ends and to the middle of each sample. The thermocouple readings are monitored for 15 to 30 min.

The steady-state conduction equations for each specimen are ratioed and solved for the conductivity ratio (candidate sample to known sample). The heat-flow ratio — needed for this calculation — is determined using the temperatures of the heated ends of the specimens to calculate the convective and radiant interchanges between the specimens and the furnace. The data-reduction procedure can be programed into a hand-held calculator. Originally applied to advanced carbon/carbon composite materials at temperatures above 3,000° F (1,600° C), this procedure should be applicable to a wide variety of materials and a wide range of temperatures.

This work was done by Charles N. Webster and James K. Willis of LTV Aerospace Corp. for **Johnson Space Center.** *No further documentation is available.*

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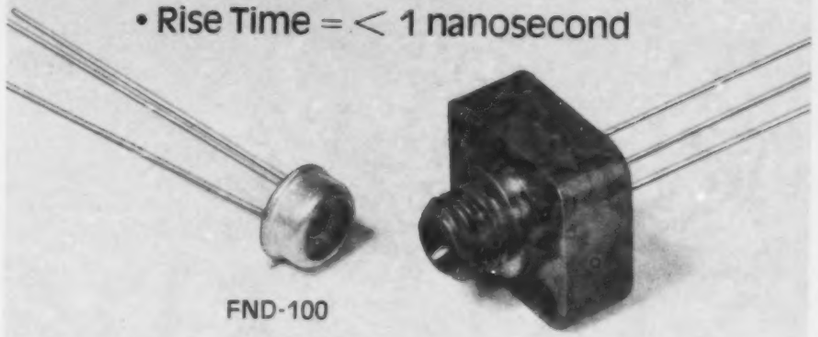

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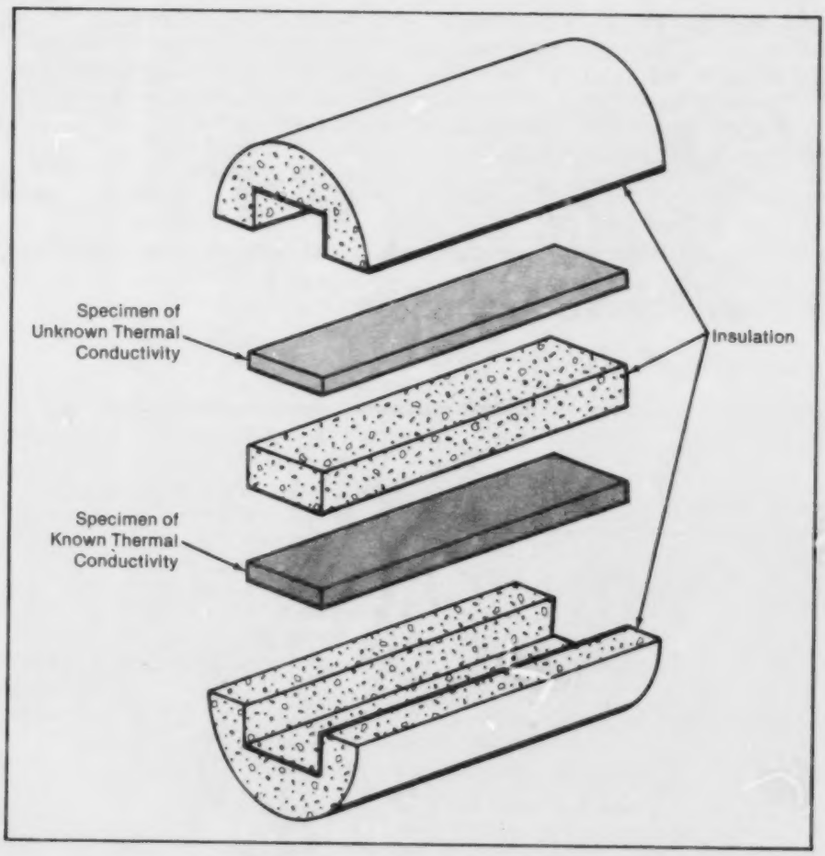

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20980.

The Two Specimens, the conductivities of which are to be compared, are placed in an assembly with insulation. One end of the assembly is then placed in a furnace. The temperature of the furnace, of each end, and of the center of each specimen are then recorded.

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Three-Dimensional Radiative-Transfer Equation

Progress is made toward the interpretation of radiometric observations.

A theoretical paper discusses the equation of radiative transfer in a three-dimensional, inhomogeneous, scattering medium illuminated from above and bounded below by a laterally-inhomogeneous, reflective plane. A representation of the radiation field with full three-dimensional variability is derived by use of a spatial Fourier transform and matrix-operator techniques developed previously for the

one-dimensional version of the problem. The equations should be useful for radiometric measurements from aircraft and spacecraft.

Initially, the problem is stated generally in terms of spatial integrals expressing the radiation incident upon, generated within, reflected from, and passing through, a horizontal planar layer. The horizontal spatial dependence of all quantities is approximated as periodic for discretization of the Fourier wave-number spectrum. In practical problems, such an approximation does not give rise to errors as long as an appropriate buffering zone is constructed within the primary pattern to prevent contamination by the adjacent repetitions of the pattern. The periodicity assumption makes it convenient to take the two-dimensional Fourier transform of the radiative-transfer equation in the horizontal plane.

Explicit expressions for the reflectivity and transmissivity operators and emission functions for an infinitesimally thin layer bounded by the z and $z + \Delta z$ planes are obtained by expansion of the Fourier-transformed radiation equations about the vertical coordinate z. By use of these operators and functions in the context of the interaction principle, expressions are obtained for the mathematical synthesis of a vertically inhomogeneous, arbitrarily thick medium. A doubling theorem makes it possible to obtain the operators and functions for an arbitrarily thick, homogeneous layer from a similar layer of infinitesimal thickness. Because a thick, inhomogeneous layer can be conveniently simulated by a vertical sequence of homogeneous layers, each in sequence having slightly different properties, the radiation-transfer functions for the entire thick, inhomogeneous layer can be built up by the combination of adding and doubling techniques.

Following the derivation described above, the basic equations are restated, and all equations are rederived in matrix form. The scattering medium is vertically stratified into a number of different layers, each of which is internally homogeneous. As before, the adding and doubling relations are derived and used to model thick layers. Although the derivations and the resulting equations are complicated, the use of the Fourier-transform, matrix-operator approach to solve practical problems is expected to be simpler than direct solution of the complete three-dimensional, linear wave equations.

This work was done by John V. Martonchik and David J. Diner of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Three-Dimensional Radiative Transfer Using a Fourier Transform Matrix Operator Method," Circle 107 on the TSP Request Card.*
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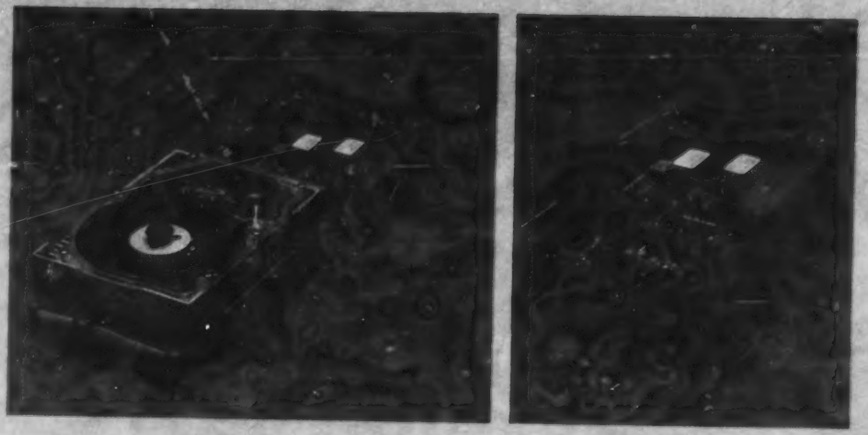

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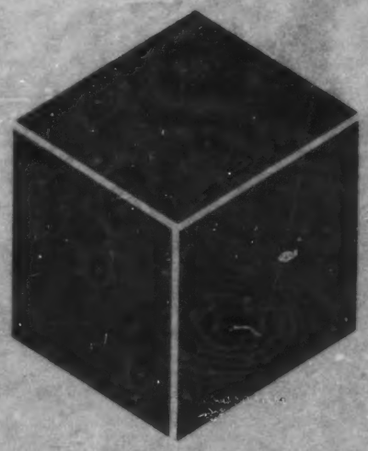

Hardware, Techniques, and Processes

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Ball-and-Socket Mount for Instruments

Jaws engage an instrument precisely but release it readily.

Marshall Space Flight Center, Alabama

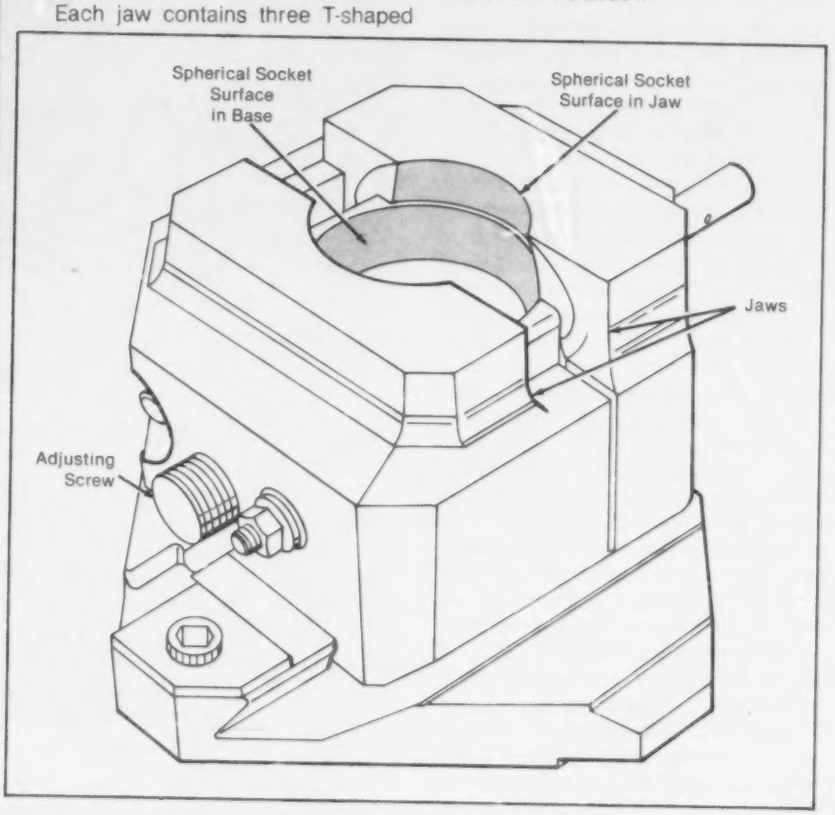
A mounting mechanism holds a scientific instrument securely, allows the instrument to be oriented, and minimizes conduction of heat to and from the instrument. The mechanism also allows quick replacement of the instrument.

The mechanism includes a stationary base containing part of the spherical-socket surface, two jaws that contain the rest of the socket surface, and an adjusting screw. A ball on the instrument sits in the spherical socket formed by the opposing jaws and base (see figure). The adjusting screw is threaded into one of the jaws and rotates in a collar in the opposite jaw. Rotating the screw counterclockwise opens the mechanism by sliding the jaws outward on a dovetail track on the base. The instrument ball can then be removed from the opened socket. Turning the screw clockwise draws the jaws together until the socket captures the ball.

Each jaw contains three T-shaped parts that maintain the alignments of the jaw parts and serve as internal stops. These parts have cylindrical arms that seat in cylindrical holes in the base as the jaws draw together. When the tees are seated, the adjusting screw is further turned to a torque of 35 lb-ft (47 N-m) to preload the mechanism and prevent the tees from separating from the base. When thus assembled, the mechanism maintains a diametral clearance of 80 to 240 μin. (2 to 6 μm) between the socket and the ball.

This work was done by Everett Kaelber of Perkin-Elmer Corp. for **Marshall Space Flight Center.** *For further information, Circle 110 on the TSP Request Card.*

Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28064.



Opposing Jaws Sliding on a Base form a socket that holds the mounting ball of a scientific instrument.

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Si_3N_4-Based Ceramic With Greater Hot Strength

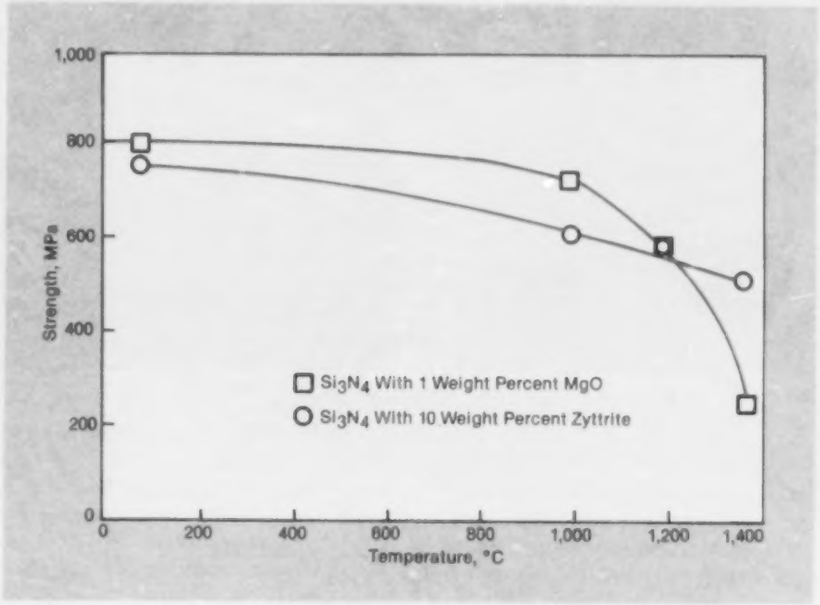
Zyttrite-doped material outperforms MgO-doped material above 1,200° C

Lewis Research Center, Cleveland, Ohio

A new ceramic material has been produced by the addition of 10 weight percent zyttrite (yttria-stabilized zirconia) to Si_3N_4 (silicon nitride) that offers significantly-improved high-temperature properties (nearly double those of MgO-doped Si_3N_4 ceramic, as shown in the figure). The work also showed that by using controlled Si_3N_4 powder with 10 weight percent zyttrite, a significant improvement in room-temperature strength can be achieved.

Advanced ceramic materials that are of great interest for a variety of high-temperature structural applications are silicon nitride (Si_3N_4) and silicon carbide (SiC). Si_3N_4 and SiC ceramics have potential for use in aircraft and automobile engines and in electric-power generating systems. These ceramics combine high thermal conductivity and low coefficients of thermal expansion and consequently have high thermal-shock resistance. Because of their high refractory nature, these ceramics are capable of operating at temperatures in the range of 2,500° to 3,000° F (1,370° to 1,650° C). However, for sintering to full density, sintering aids are required that often form a glassy phase at the grain boundaries. In Si_3N_4, a glassy phase is responsible for strength loss at high temperatures.

With the new ceramic material, time-dependent flexure tests showed very little strength degradation at 1,400° C (2,552° F).



The **Four-Point-Bending Strengths** of two Si_3N_4-based ceramics are compared at different temperatures.

The creep resistance at 1,350° C (2,462° F) was one to two orders of magnitude better than Si_3N_4 materials containing MgO and Y_2O_3 as sintering aids. Further, the Weibull modulus "m" (for 30 test bars) was estimated to be 17, which is relatively high for Si_3N_4 materials, and the oxidation resistance at 1,370° C (2,500° F) in air compared favorably to the oxidation resistance of silicon carbide material. These improved properties strongly suggest that the 10-weight percent zyttrite/Si_3N_4 material has a strong potential for high-temperature applications.

This work was done by Sunil Dutta and Bruno Buzek of **Lewis Research Center.** *For further information, Circle 93 on the TSP Request Card.* *LEW-14193*

Compression-Failure Mechanisms in Composite Laminates

Failure mechanisms are observed using transparent fiberglass/epoxy birefringent materials.

Langley Research Center, Hampton, Virginia

The efficient use of composites in aircraft structural components requires a thorough understanding of the failure mechanisms of these materials. The opaqueness of graphite/epoxy laminates prevents direct observation of the mechanisms involved in the initiation and propagation of damage. Although destructive failure-assessment methods are available, the sequence of failure within the laminate is difficult to determine using these methods.

An in situ nondestructive technique was developed to observe failure as it develops and as it propagates within the laminate. This technique is based on the use of a transparent fiberglass/epoxy birefringent material. The transparency allows visual observation of the location of initial laminate failure and of the subsequent failure propagation; the birefringence

allows the laminate stress distribution to be observed during the test and also after the test if permanent residual stresses occur.

Two $(+45_4/-45_4)_{2s}$ fiberglass/epoxy specimens, each with a single, centrally-located circular hole, were tested. The specimens were fabricated from commercially-available glass cloth preimpregnated with epoxy resin. Specimens were nominally 6.0 by 3.0 by 0.11 in. (15.2 by 7.6 by 0.28 cm), and the hole diameters were 0.19 and 0.50 in. (0.48 and 1.27 cm).

The specimens were tested by slowly applying a compressive end load to simulate a static loading condition. The ends were machined flat and parallel to permit uniform compressive loading. Loaded edges were clamped by fixtures during testing while unloaded edges were supported by knife-edge restraints to prevent the specimen from buckling as a wide column. The polarizer and analyzer were oriented at $+45°$ and $-45°$, respectively, to the load axis.

Experimental results shown in Figures 1 and 2 illustrate the value of the birefringent material for observing the failure of composite specimens. The specimens in Figure 1 were loaded and then unloaded. When these unloaded specimens were illuminated with polarized light, the isochromatic fringe patterns indicated that plastic deformation had occurred.

The pattern on specimen A indicates that high stresses exist in bands oriented at $\pm 45°$ to the load axis. For this uniaxially loaded laminate, the in-plane shear stress is a maximum on elements oriented 45° to the applied load, resulting in high stresses in the epoxy matrix between fibers. The high stresses in the bands in specimen A are caused by in-plane fiber/matrix shearing in these regions and are identified as matrix-shearing bands in the figure. While the specimen was being loaded, these bands initiated at the hole boundary and grew toward the specimen edges.

Specimen B was loaded further into the plastic range than was specimen A. This specimen also has matrix-shearing bands, but the isochromatic fringes are not observed in the region of these bands. While the specimen was being loaded, severe internal damage occurred within the bands, disrupting the light path and destroying the birefringence. The damage was caused by local delamination and in-plane shearing failure mechanisms.

When this specimen is illuminated with white light (Figure 2), the damage in the matrix-shearing bands is indicated by the $\pm 45°$ dark bands. The damage is most severe at the two locations where the hole boundary intersects the horizontal centerline of the specimen: the locations

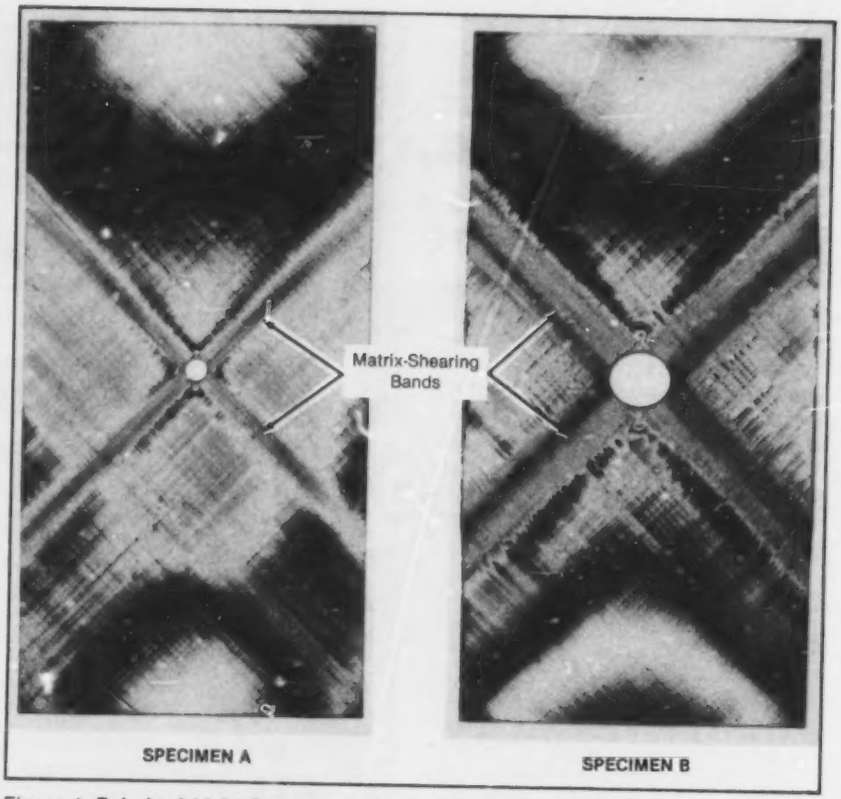


Figure 1. **Polarized Light Reveals** matrix-shearing bands in damaged regions of the specimen.

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where damage initiated.

Closer inspection of the damaged regions reveals a fiber-kinking mechanism. The kinking results from a +45° layer partially restraining the in-plane shearing occurring in an adjacent −45° layer, or vice versa. The fiber kinking occurs without fiber breakage due to the flexibility in the matrix provided by extensive shear failures.

The transparency and birefringence properties of the fiberglass/epoxy material enable regions of high stress to be located and the mechanisms of local failure and of failure propagation to be identified within the laminate. This fiberglass/epoxy material may also be useful for studying stress fields and for identifying failure initiation and propagation mechanisms in a wide variety of composite structures.

This work was done by Mark J. Shuart, Jerry G. Williams, and Paul A. Cooper of **Langley Research Center.** *Further information may be found in:*

NASA CR-165709 [N81-26183/NSP], "Development of Orthotropic Birefringent Materials for Photoelastic Stress Analysis" [$10], and

NASA TM-86306 [N84-20259/NSP], "Investigating Compression Failure Mechanisms in Composite Laminates with a Transparent Fiberglass-Epoxy Birefringent Material" [$7].

Copies of these reports may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.

LAR-13345

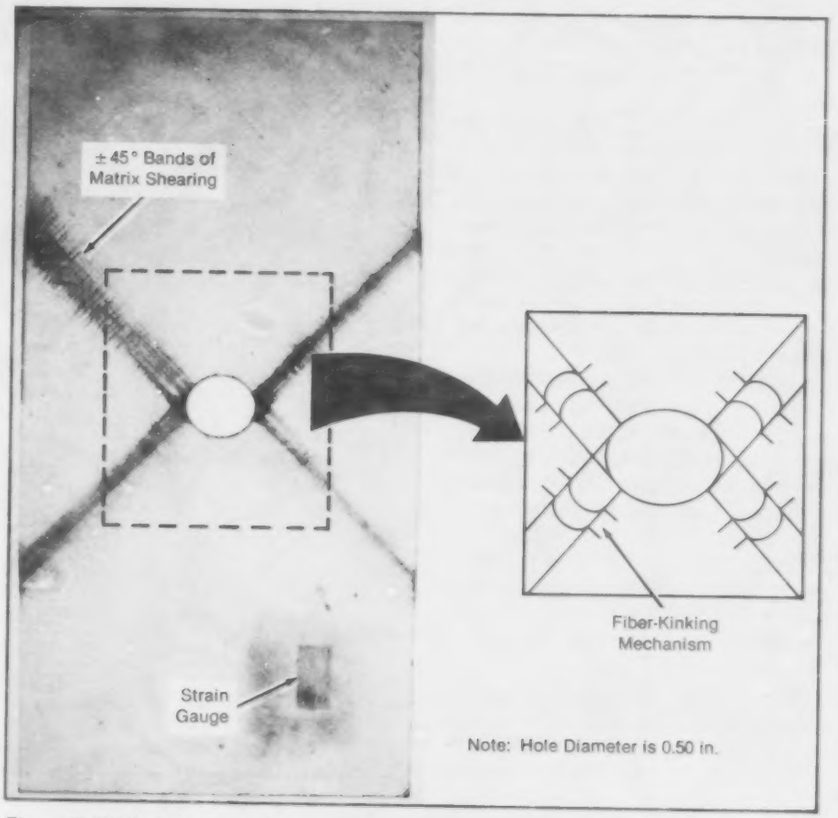

Figure 2. **White Light Reveals** matrix-shearing bands plus a fiber-kinking mechanism.

Detoxification of Halon Fire-Extinguishant Products

Ammonia compounds absorb toxic hydrogen halides as they are produced.

Lyndon B. Johnson Space Center, Houston, Texas

Toxic acid vapors resulting from the use of Halon (or equivalent) fire extinguishers are immediately changed into nontoxic ammonium compounds when the extinguishers contain some ammonia or ammonium carbonate. If ammonium carbonate is used, the particle size of the resulting neutral compounds can be controlled to eliminate virtually any absorption into the lungs.

When used to extinguish a fire, a Halon (halogenated hydrocarbon) is partially decomposed to form hydrogen fluoride, chloride, or bromide, which are toxic, irritating, and corrosive vapors. In some instances lethal concentrations of these gases are formed.

However, when the Halon fire extinguishers contain powdered ammonium carbonate, aqueous ammonia, or ammonia gas, the ammonia compound is discharged with the Halon and reacts with the toxic vapors to produce solid, nontoxic, nonirritating, and much less corrosive ammonium halides. These are stable at all pressures and temperatures up to 300° C. (When ammonium carbonate is used, water and carbon dioxide are also produced as byproducts.)

The quantities of ammonia or ammonium carbonate placed in the extinguishers are about three times the stoichiometric amounts required to neutralize the quantities of acid gases formed by the extinguishing process, as determined in previous tests. Ammonium carbonate is a dry powder and aqueous ammonia is a liquid; neither is significantly soluble in any Halon extinguishing agent. Theoretical considerations and actual test results have demonstrated that the presence of ammonium carbonate or aqueous ammonia in the extinguishing agent impairs neither its capacity nor its rapidity of extinguishment.

In a White Sands Test Facility application, in which a diesel fuel fire within a 600-ft^3 (17-m^3) armored personnel carrier was extinguished, 250 g of ammonium carbonate, or 250 ml of aqueous ammonia were added to the Halon extinguishing compound. The estimated amount of Halon 1301 required to extinguish a fire in this volume is 4.4 kg. Therefore, the weight of the ammonium carbonate (250 g) added to the extinguisher is only 5.6 percent of the weight of the Halon 1301 —

amounting to a negligible increase in extinguisher weight.

This work was done by Eric L. Miller of Lockheed Engineering & Management Services, Inc., for **Johnson Space Center.** *No further documentation is available.*

Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20962.

Phosphazene Polymers Containing Carborane

The addition of carborane may increase thermal stability.

Ames Research Center, Moffett Field, California

Polymer	Nitrogen Atmosphere			Air Atmosphere		
	Polymer Decomposition Temperature, °C	Temperature of Maximum Rate of Weight Loss, °C	Percent Char Yield at 900° C	Polymer Decomposition Temperature, °C	Temperature of Maximum Rate of Weight Loss, °C	Percent Char Yield at 800° C
Poly(phenylcarboranyltrifluoroethoxy)phosphazene	110	395	61	110	380	57
Same as Above but Dried at 75° C for 18 h	120	465	59	130	495	65
Poly(2,2,2-trifluoroethoxy)phosphazene	370	410	0	180	412	0

Char Yields and Decomposition Temperatures of two phosphazene polymers are compared.

Carborane-substituted polyphosphazenes have been prepared by the thermal polymerization of phenylcarbonyl-pentachlorocyclotriphosphazene followed by reaction with sodium trifluoroethoxide to replace the remaining chlorine atoms with trifluoroethoxy groups. These improved polymers offer high char yields and resistance to hydrolysis.

Organophosphazene polymers offer a valuable combination of properties: They are resistant to some alkalis and acids, water- and oil-repellent, fire-resistant, and flexible at temperatures as low as −80° C. The alternating phosphorus and nitrogen atoms in the backbone of the polymers give them torsional mobility and a low glass-transition temperature and make them transparent to ultraviolet radiation.

Polydichlorophosphazenes are susceptible to hydrolysis, but are made immune by replacing the chlorine atoms with aryl, alkyl, amino, alkoxy, and aryloxy groups. The resulting hexachlorocyclotriphosphazene trimer is then hydrolyzed to oxophosphazene. Unfortunately, this product, while resistant to hydrolysis, is thermally unstable. The polymer can be stabilized, however, if carborane is added before replacing the chlorine.

The synthesis of the improved polymer requires the prior synthesis of a number of reactants, including phenyl-lithiocarborane, hexachlorotriphosphazene (I) trimer, and sodium trifluoroethoxide. The carborane is introduced by the reaction of the phenyl-lithiocarborane with the hexachlorotriphosphazene (I) trimer. The purified product of this reaction is thermally polymerized by heating to 250° C. The resulting polymer is reacted with the sodium trifluoroethoxide.

In one of the thermal-stability tests of the carborane-containing material, an aluminized mirror coated with a film of the polymer was subjected to successive vacuum pyrolyses. After each episode of pyrolysis, the polymeric residue was examined for structural changes by infrared spectroscopy. The following changes were observed:

- Up to 200° C, the material first lost

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weight by giving off low-molecular-weight compounds and products resulting from the pickup of atmospheric moisture;

- At 300° C, the polymer lost borane and trifluoroethoxy groups; the loss of trifluoroethoxy groups resulted in cross-linking between the phosphazene chains and a more thermally stable residue;
- At 400° C, the polymer lost most of the remaining carborane; and
- Pyrolysis above 400° C resulted in no further changes discernable by infrared spectroscopy.

Thermogravimetric analysis was performed in dry nitrogen and in air. Although the polymer decomposition temperatures were lower than those of a phosphazene polymer without carborane, the char yields were much higher, as shown in the table.

This work was done by L. L. Fewell and J. A. Parker of **Ames Research Center** *and R. J. Basi of San Jose State University. For further information, Circle 4 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center *[see page 29].* *Refer to ARC-11487.*

Room-Temperature Deposition of NbN Superconducting Films

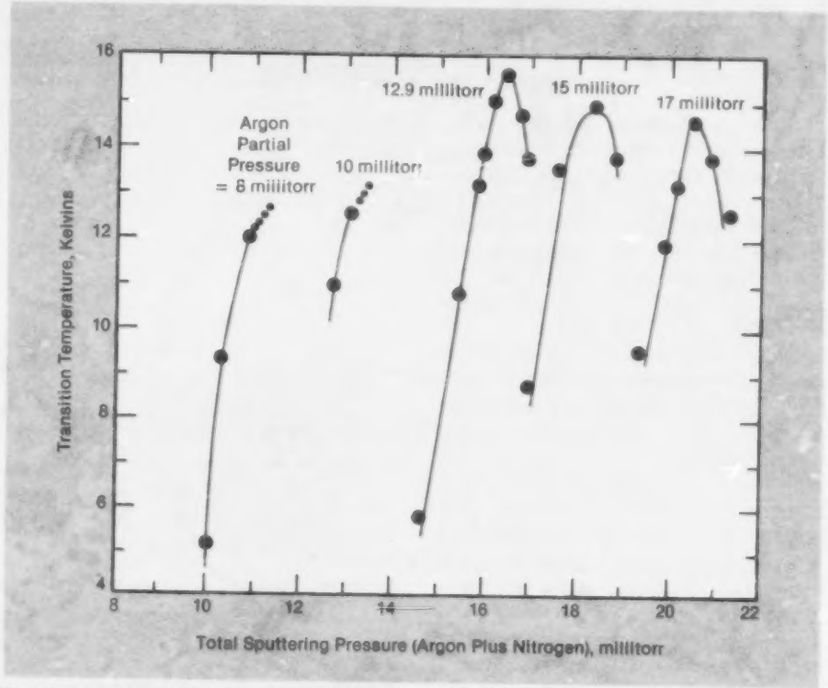
Films with high superconducting transition temperatures are deposited by reactive magnetron sputtering.

NASA's Jet Propulsion Laboratory, Pasadena, California

Thin films of refractory niobium nitride with superconducting transition temperatures (T_c) as high as 15.7 K have been deposited on glass, fused quartz, and sapphire substrates by dc reactive magnetron sputtering in a mixture of Ar and N_2 gases. Although substrate temperature increased gradually during the sputter deposition process, it never rose above ~90° C. Since this deposition process does not involve significantly high substrate temperatures, it can be employed to deposit a counter electrode in a superconductor/insulator/superconductor junction without causing any thermal or mechanical degradation of the underlying delicate tunneling barrier. Furthermore, substrates for the room-temperature deposition of NbN could be polymeric or coated with photoresist, making the films accessible to conventional lithographic patterning techniques.

A planar magnetron sputtering source with a 2-in. (5.08-cm) diameter, 0.125-in. (0.318-cm) thick niobium target (99.91 percent pure) was used to deposit the NbN films onto the precleaned substrates fixed on a substrate holder located about 2.75 in. (6.98 cm) from the target. An oil-free ultra-high-vacuum system was evacuated to a background pressure of around 8×10^{-8} torr (1×10^{-5} N/m^2) by a 300-l/s ion pump, further supported by a titanium cryosublimation pump. The sputtering was carried out in a reactive gas mixture of 99.999-percent pure argon and nitrogen, the flow rates of which were controlled by independent flowmeters. The pressure in the chamber was monitored by a capacitance manometer. A Chromel/Alumel thermocouple was mounted on a control substrate to monitor the substrate temperature during sputter deposition.

In each run, the voltage was adjusted to a value between 320 and 350 volts to obtain a constant discharge current of about 1 ampere. The flow rates varied in the ranges of 2 to 4 standard cubic centimeters per minute for Ar and 0.3 to 1 standard cubic centimeters per minute for N_2. Both the flow rates and the chamber pressure were closely monitored. Sets of NbN films were deposited under various partial pressures of argon, ranging from about 5 to about 17 millitorr (0.7 to 2.3 N/m^2), mixed in each case with different partial pressures of nitrogen in the range of 2 to 6 millitorr (0.3 to 0.8 N/m^2).



The Temperature (T_c) of the Superconducting Transition in the deposited NbN film depends on the argon and nitrogen pressures in the sputtering chamber.

The films with relatively high T_c have face-centered-cubic crystal structure (like that of NaCl) as revealed by their X-ray diffraction patterns. An initial increase in the injection pressure of N_2 for a constant argon pressure results in a remarkable increase in the (111) diffraction line intensity due to a strong orientation of the film with the (111) direction perpendicular to the substrate plane. This increase correlates distinctly with an increase in the T_c (see figure). However, beyond a threshhold, a further increase in the N_2 injection pressure causes a distortion of the crystal structure towards the lower-stoichiometry (NbN_x, $x<1$) tetragonal

phase, accompanied with a reduction in the T_c.

The films with the high transition temperature (T_c = 15.7K) had a superconducting transition width of about 0.2K. This could be attributed to slight gradients in the stoichiometry and/or microstructure of the films along their thickness. Further refinements in the deposition technique may yield films with smaller transition widths, the T_c of which might approach the predicted value of 18 K.

This work was done by Sarita Thakoor, James L. Lamb, Anilkumar P. Thakoor, and Satish K. Khanna of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 31 on the TSP Request Card.*
NPO-16681

Increasing the Cryogenic Toughness of Steels

Grain-refining heat treatments increase toughness without substantial strength loss.

Langley Research Center, Hampton, Virginia

High-strength, high-toughness steels are often required in applications involving the safety and reliability of components exposed to cryogenic temperatures. Fuel tanks and pressure vessels on aircraft and spacecraft are good examples. Unfortunately, strength must often be traded off against fracture toughness: the higher the yield strength, the lower the fracture toughness. The so-called "technological limit" represents the highest attainable toughness for a given strength level, considering all available alloys.

NASA has developed two high-Reynolds-number cryogenic wind tunnels that can subject aircraft-component models to high windloads at very low temperatures. These conditions require that the models be constructed from steels with strength and toughness values above the current technological limit. One way to increase toughness without trading too much strength in a given alloy is to refine its grain size. In the iron/nickel/cobalt steels of interest, grain refinement can be achieved by cycling the material across the austenite/austenite-plus-ferrite phase-transformation boundary. Therefore, a program was initiated to investigate the improvement of the fracture toughness of several iron/nickel/cobalt alloys by grain refinement through heat treatment.

Five alloys were selected for study, all of them at or near the technological limit. Production plates of these alloys were the baseline materials against which all improvements in properties were measured. Standard Charpy V-notch specimens were machined from plates that had been given various grain-refining heat treatments. These treatments involved several cycles of heating the material above the austenite or austenite-plus-ferrite transformation temperature, holding for various intervals, and quenching in water. After heat treatment, Charpy V-notch tests and tensile tests were performed at 77 K (−321° F), followed by optical and scanning electron microscopy.

The results showed clearly that the grain sizes of these alloys could be refined by such heat treatments and that the grain refinement could indeed result in a large improvement in toughness without a substantial loss in strength. The best improvements were seen in HP-9-4-20 Steel, at the low-strength end of the technological limit, and in Maraging 200, at the high-strength end. These alloys, in the grain-refined condition, are being considered for model applications in the high-Reynolds-number cryogenic wind tunnels.

This work was done by Homer F. Rush of **Langley Research Center.** *Further information may be found in NASA TM-85816 [N84-30014/NSP], "Grain-Refining Heat Treatments To Improve Cryogenic Toughness of High-Strength Steels" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
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Impact-Resistant Ceramic Coating

Refractory fibers more than double the strength of the coating.

Lyndon B. Johnson Space Center, Houston, Texas

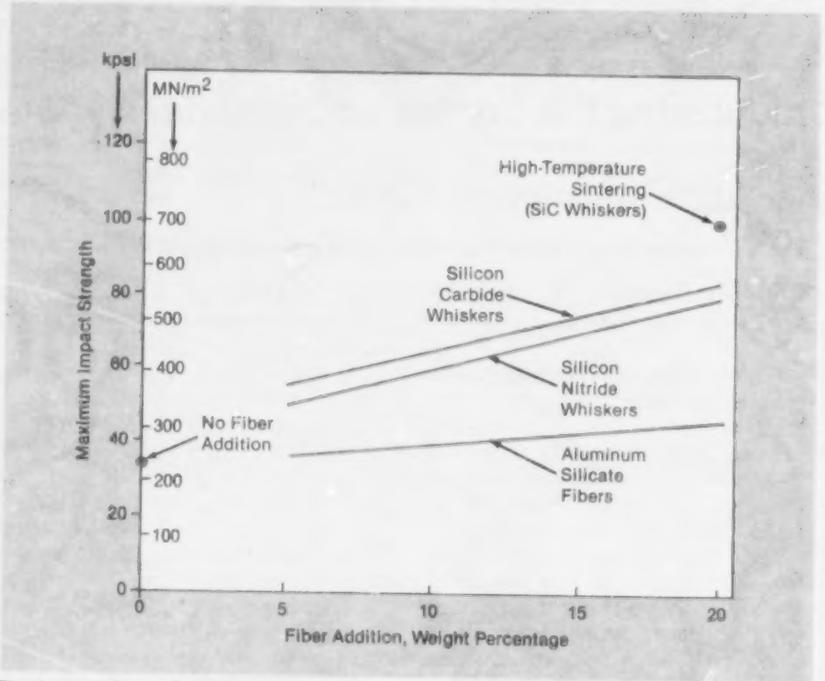
A coating for ceramic insulating tiles has increased impact strength as well as high thermal emittance. The addition of whiskerlike ceramic fibers in controlled amounts to the standard coating for Space Shuttle insulating tiles increases the impact strength to about 2½ times that of the standard coating alone. The new coating can also be used to improve the thermal and mechanical properties of electromagnetic components, mirrors, furnace linings, and ceramic parts for advanced internal-combustion engines.

The whiskers may be aluminum silicate, silicon carbide, or silicon nitride. They should have a high fiber aspect ratio (the ratio of length to diameter) for greatest effectiveness.

In comparative tests, each of the three types of whiskers was blended into a slurry of the standard coating material in proportions of 5, 10, 15, and 20 percent by weight. The mixtures were applied to tiles and baked at 2,250° F (1,232° C) for 90 minutes. The impact strengths of the coated tiles were then measured in an impact-testing apparatus in which the fractures of the coatings were detected acoustically.

For all whisker materials, the impact strength increased with the amount of the additive (see figure). Silicon carbide whiskers produced the greatest increase in impact strength. The strength of the silicon carbide coating was increased even further by sintering at 2,400° F (1,300° C) for 60 minutes.

The formation of cristobalite, which causes microcracking of the coating, was not a problem, even after long exposures to high temperatures. X-ray diffraction tests of the coatings after 15 hours at 2,300° F (1,260° C) showed that the concentration of cristobalite was within acceptable levels.



The Impact Strengths of Ceramic Coatings increase with increasing whisker content. Silicon carbide whiskers clearly produce the largest increase, and the improvement grows even more with high-temperature sintering.

The whisker-reinforced coating can be applied and processed by methods that are compatible with existing production equipment. The reinforcement concept is adaptable to other refractory coating and can lend them improved impact resistance without detracting from other properties.

This work was done by William H. Wheeler, John F. Creedon, and Yamato D. Izu of Lockheed Missiles & Space Co., Inc. for **Johnson Space Center.** *For further information, Circle 57 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center *[see page 29].* *Refer to MSC-20829.*

Carbon Shields for Intercalated Fiber Conductors

Stability in air is increased by depositing amorphous carbon.

Lewis Research Center, Cleveland, Ohio

Intercalated graphite-fiber conductors are more or less air-stable at room temperature. However, the uncoated intercalated fibers can react with oxygen, moisture, and other chemicals surrounding the conductor, causing it to lose desirable properties. Their stability in air and moisture at ambient and elevated temperatures is greatly enhanced by the use of a protective shield. The protective shield coats the fiber after intercalation, preventing reactive gases or liquids from interacting with the intercalation compound and the intercalant from leaving the fiber.

Initially the graphite fibers are intercalated (insertion of atoms or molecules between the graphite layers), which changes (lowers) the electrical resistivity and makes the fibers metallic-like. The intercalant species used should be of those found to form intercalation compounds that lower the electrical resistivity. Copper chloride, bromine, and arsenic pentafluoride are examples of materials that have worked well in the past.

As the next step, the conductor is

coated with a diamondlike amorphous carbon. This coating is applied in the same chamber as the intercalation reaction, or an alternate deposition chamber can be used. The deposition of carbon can be accomplished by any number of techniques. Ion-beam sputter-deposition and RF plasma techniques have been used, but dc plasma and others will work also.

In addition to a pure carbon coating, other combinations will work. The best example is amorphous silicon/carbon in varying ratios of the two elements. A coating of several hundred to a few thousand angstroms in thickness is in the desired range. Thickness, however, is not a critical factor in performance as long as complete coverage of the surface is obtained. Potential uses include conductive epoxy composites, tether conductors, signal wire, and power cables.

This work was done by Bruce A. Banks of **Lewis Research Center** *and John A. Woollam of the University of Nebraska. Further information may be found in NASA TM-81721 [N81-21129/NSP], "Ion Beam Applications Research — a 1981 Summary of Lewis Research Center Programs" [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 29]. Refer to LEW-14063.

Producing Large-Particle Monodisperse Latexes

A process using seed particles offers a large-size, uniform product.

Marshall Space Flight Center, Alabama

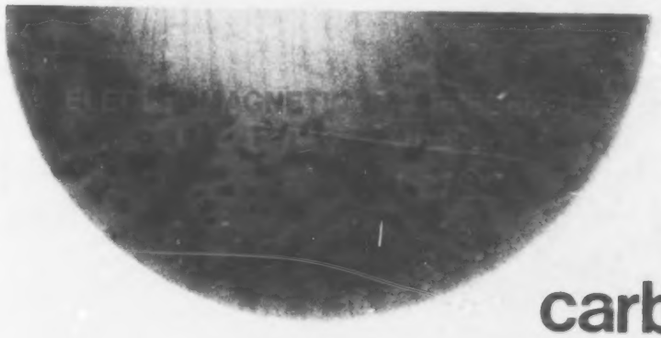
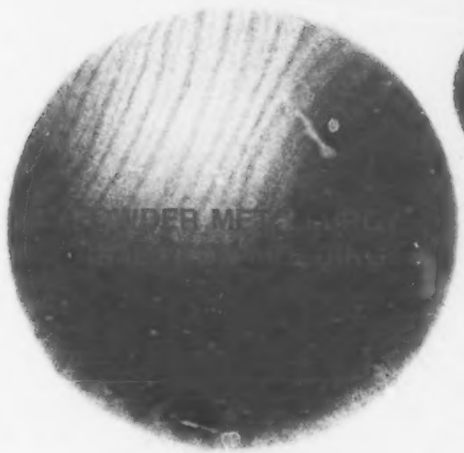
A chemical process produces latex particles of relatively large, uniform size for use as size standards for instrument calibration. The process, based on seeding of a mixture by very small latex particles, yields particles measuring 2 to 30 μm or more in average size. It produces monodisperse latexes — those in which the deviation from the average size is less than 2 percent. The particles can therefore be used directly, without the tedious separation procedures for removing the off-size particles.

The process is efficient. The quantity of coagulum byproducts is low. Previous processes have been hampered by poor uniformity, inadequate particle size, and inefficient use of materials.

In the microgravity environment of space, the process creates monodisperse latexes of even larger size. Particles of 100 μm or more are possible. In these cases, it is estimated that particle yields can reach as much as 50 percent by weight of the reaction mixtures.

The starting mixture for the process consists of the following:

- 2 to 30 parts (by weight) of a monodisperse seed latex (particle size about 2 μm);
- 10 to 50 parts of a polymerizable, monofunctional (noncross-linking) monomer;
- Up to 0.1 parts of a polyfunctional (cross-linking) monomer;
- 0.01 to 0.2 parts of an initiator that is soluble in the monomer and less soluble in water;
- 0.001 to 0.1 parts of an inhibitor that is soluble at least in water;
- Up to 2 parts of a mixture of poly-

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meric, comonomeric, and anionic emulsifiers; and
- Enough water to make 100 parts by weight.

The formulation is mixed to form an emulsion and agitated mildly for 8 to 24 hours at a temperature below the decomposition temperature of the initiator. This step swells the seed particles. The inhibitor prevents the radicals from forming in the water phase of the emulsion during this part of the process. The mixture is then polymerized by heating it above the decomposition temperature of the initiator — typically at 60° to 90° C — for 10 to 30 hours under continued mild agitation.

The procedure can be repeated to create larger particles; that is, the monodisperse product of polymerization can be used as seed particles. Several generations of increasingly larger monodisperse particles can be produced.

This work was done by John W. Vanderhoff of Lehigh University for **Marshall Space Flight Center.** *For further information, Circle 109 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-26026.

Process Produces Low-Secondary-Electron-Emission Surfaces

A textured carbon layer is applied to copper by sputtering.

Lewis Research Center, Cleveland, Ohio

A process has been developed for applying a very thin layer of highly textured carbon to a copper surface by a sputtering technique. The carbon surface is characterized by a dense, random array of needle-like spires or peaks that extend perpendicularly from the local copper surface. The spires are approximately 7 micrometers in height and are spaced approximately 3 micrometers apart, on the average.

An electron microscope photomicrograph of a typical surface is presented in Figure 1. The copper substrate is essentially completely covered by the carbon layer, which is tenacious and not damaged by vibration loadings representative of multistage depressed collector (MDC) applications.

The process was developed primarily to provide an extremely low-secondary-electron-emission surface for copper for use as high-efficiency electrodes in MDC's for microwave amplifier traveling-wave tubes (TWT's). These tubes are widely used in space communications, aircraft, and terrestrial applications.

One of the significant factors in maximizing MDC efficiency is the use of electrode materials having low-secondary-electron-emission characteristics. Specifically, to recover the maximum kinetic energy from the spent electron beam after it has passed through the TWT's interaction (signal-amplifying) section and entered the MDC, the electrodes must have low-secondary-electron-emission characteristics so that the impinging electrons are not excessively reflected or reemitted from the surfaces. In an untreated condition, copper surfaces have relatively very high-secondary-electron-emission levels.

The carbon surface is applied by means of a triode sputtering process, in which a carbon target and copper substrate are simultaneously exposed to an argon plasma in a low-pressure environment. Other than the removal of oxide or oil or dirt from the copper by simple abrasion of the surface, no special pretexturing treatment of the copper is required. The carbon target and copper substrate are held at the same potential relative to the plasma during the texturing process.

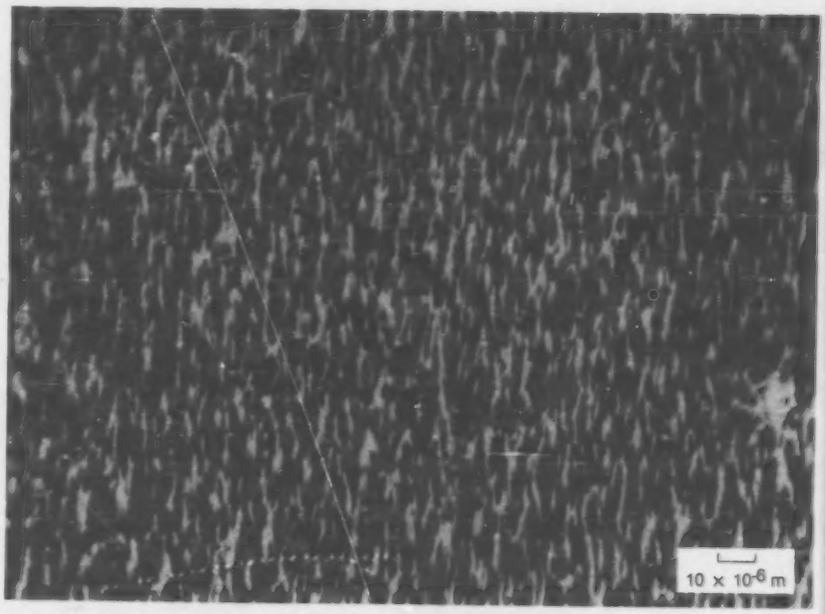

Figure 1. **Textured-Carbon Surfaces** on a copper substrate are shown here on an electron microscope photograph. The angle with the surfaces is 30°.

In a typical case, where the substrate is circular in shape, the carbon target closely surrounds the substrate and is shaped so that its surface slopes radially upward and outward at an angle of approximately 45°. Further, the target is positioned approximately one-half the diameter of the substrate above the surface of the substrate to promote uniform application of the textured carbon layer.

Most of the electrons in a primary electron beam that impinges the textured carbon layer strike the conical sloping walls of the spires or the base of the spires. Secondary electrons that are then emitted from these regions are repeatedly intercepted (with consequent repeated partial retention) by nearby adjacent spire walls, thereby greatly reducing net emission from the normal projected surface area. The highly textured surface, therefore, is the principal factor in producing the extremely low-secondary-electron-emission characteristics exhibited by this material.

The true secondary-electron-emission ratio; i.e., the ratio of low-energy-emitted electrons to impinging electrons is shown in Figure 2(a), and the reflected primary electron yield, indexed to that of a carbon-

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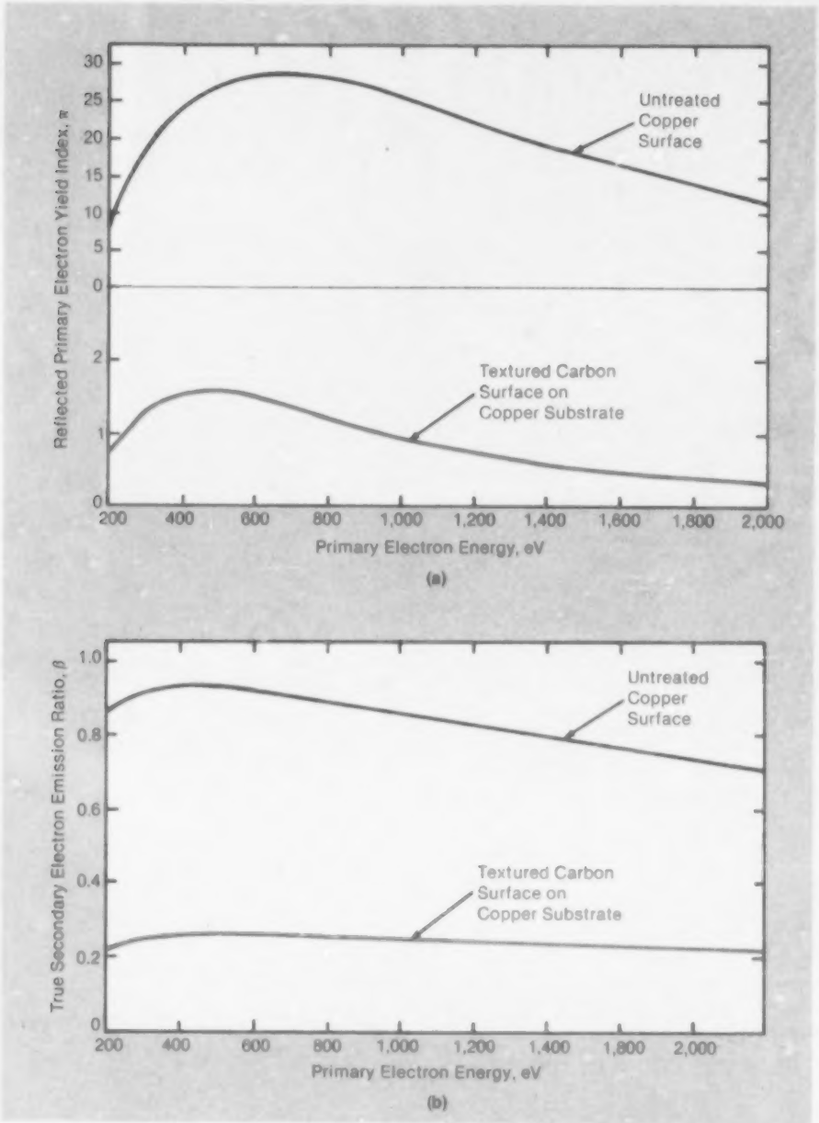

Reflected Primary Electron Yield Index, π
Untreated Copper Surface
Textured Carbon Surface on Copper Substrate
Primary Electron Energy, eV
(a)
True Secondary Electron Emission Ratio, β
Untreated Copper Surface
Textured Carbon Surface on Copper Substrate
Primary Electron Energy, eV
(b)

coated control surface at 1,000 eV primary beam energy, is shown in Figure 2(b). For comparison, chacteristic curves for untreated copper are also shown. The sharply lower emission levels for the carbon-coated surface relative to those of untreated copper are clearly evident.

While developed primarily for the MDC electrode application, the process should have many other potential uses in other electron devices and components where low-secondary-electron emission is desirable. These uses might include power tube grids, output waveguide transformers, waveguides, and other related applications.

This work was done by Arthur N. Curren, Kenneth A. Jensen, and Robert F. Roman of **Lewis Research Center.** *For further information, Circle 41 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 29]. Refer to LEW-14130.

Figure 2. The **Reflected Primary Electron Yield Index** is plotted in (a) as a function of electron energy. In (b), the true secondary electron emission ratio is plotted against primary electron energy.

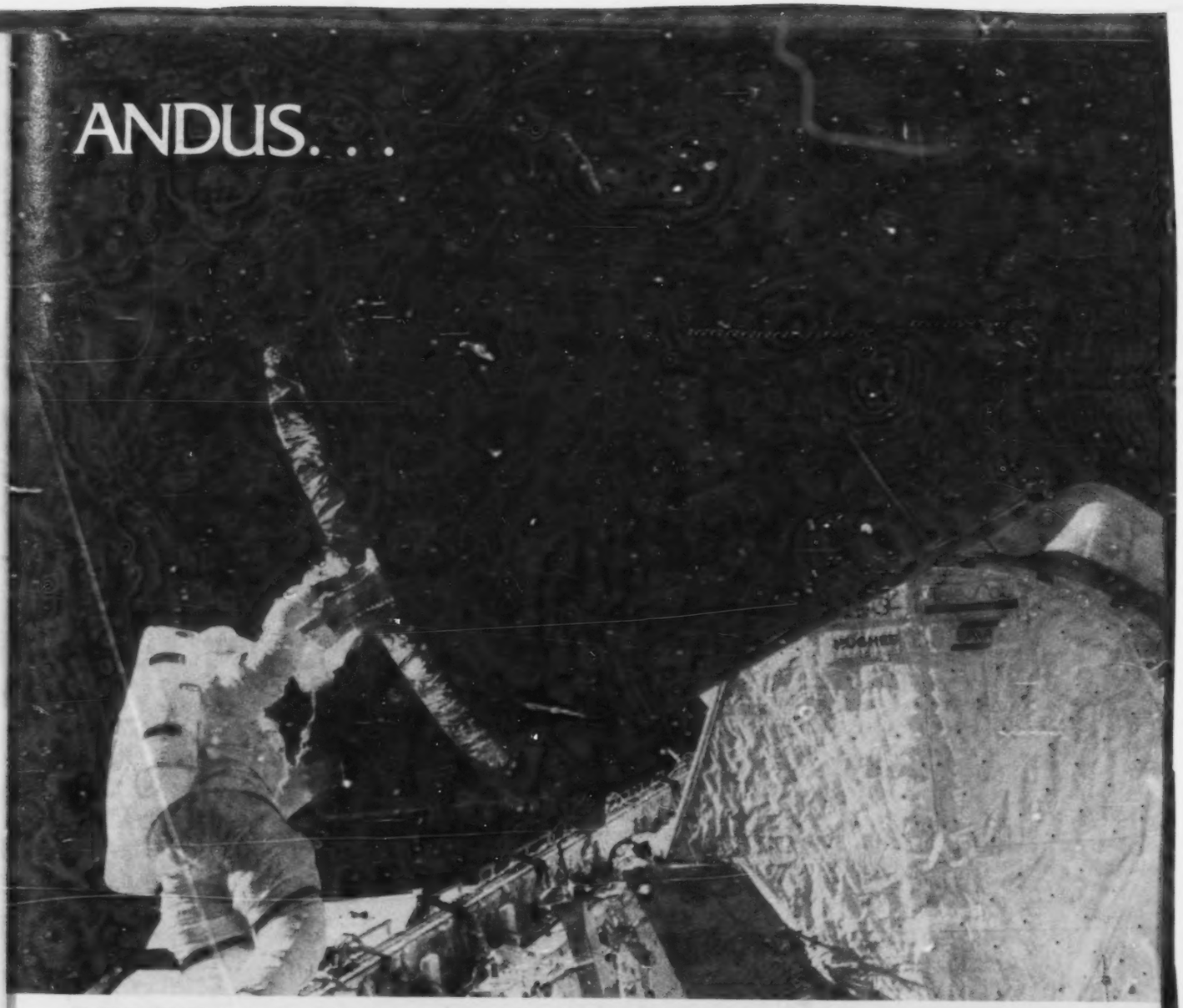
Antisoiling Coatings for Solar-Energy Devices

Fluorocarbons resist the formation of adherent deposits.

NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental program has identified promising coating materials that can reduce the soiling of solar photovoltaic modules and possibly solar thermal collectors. Contaminating layers of various degrees of adherence (see figure) form on the surfaces of these devices, partially blocking the incident solar energy, which reduces the output power. Loose soil deposits during dry periods but is washed off by rain. The new coatings help to prevent the formation of the more-adherent, chemically and physically bonded layers that rain alone cannot wash away.

Prior research had shown that a soil-resistant surface must be hard, smooth, hydrophobic, low in surface energy, and chemically clean of sticky materials.



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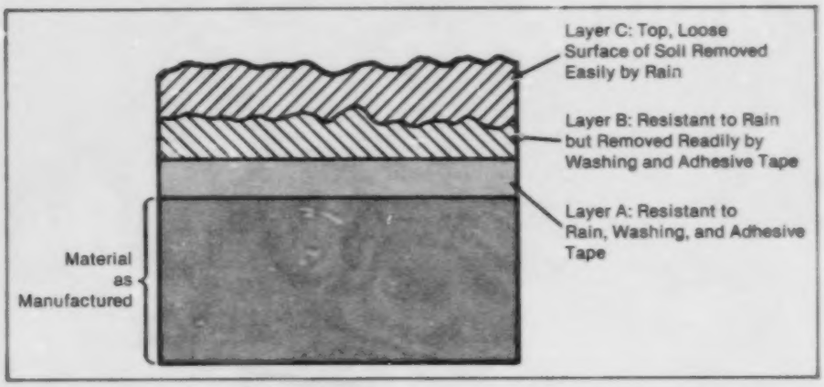
water-soluble salts, and first-period elements, both on and below the surface. It must also be resistant to ultraviolet photo-oxidation, hydrolysis, or both. The base-material/coating combinations most likely to satisfy these requirements are a hard, smooth flurocarbon and a fluorocarbon coating a few microns thick on a hard, smooth backing such as glass.

Candidate materials for the outer coverings of photovoltaic modules include low-iron glass, Tedlar (or equivalent) polyvinyl fluoride (PVF), and Acrylar (or equivalent) biaxially-oriented acrylic film. These materials are all hard, smooth, and free of water-soluble residues.

Two candidate fluorocarbon coating materials were selected. One is L-1668 (or equivalent), an experimental silane used to impart water- and oil-repellency to glass. The other is E-3820 (or equivalent), an experimental compound obtained by reacting perfluorodecanoic acid with Z-6020 (or equivalent), a commercial silane. Both compounds bond chemically to glass surfaces and both are supplied in solvent solutions.

The coatings were applied by brushing, followed by curing and drying in air for 24 hours. The samples were then tested for adherence of the coatings by observing the degree of hydrophobicity after immersion in water.

Without special surface preparation, both coatings adhered to glass; the E-3820 adhered to the PVF; and the L-1668, to the acrylic. When the PVF and acrylic surfaces were activated by exposure to ozone, the L-1668 then adhered to the PVF, and the E-3820 adhered to the acrylic.


Layer C: Top, Loose Surface of Soil Removed Easily by Rain
Layer B: Resistant to Rain but Removed Readily by Washing and Adhesive Tape
Layer A: Resistant to Rain, Washing, and Adhesive Tape
Material as Manufactured

Soil Deposits on a Weathering Surface in three layers, as shown in this simplified cross section. The antisoiling coatings described in the text help to prevent the formation of tenacious layers A and B.

Uncoated and coated glass and plastic samples were mounted in outdoor racks. A record of rainfall was kept to correlate soiling effects with precipitation. The degree of soiling was monitored by measuring the decrease in short-circuit current output of a standard silicon solar cell covered by a sample.

Of the uncoated samples, glass had the least tendency to retain soil, followed by PVF and acrylic. With the fluorocarbon coatings, however, the soiling behavior of all three materials was essentially the same. The best substrate/coating combinations were glass with E-3820, PVF with E-3820, and ozone-treated acrylic with E-3820. The time-averaged optical losses of the coated substrates compared to those of the same substrates uncoated were 1.55/2.65, 1.70/5.38, and 2.59/7.20 percent for glass, PVF, and acrylic, respectively.

This work was done by Edward F. Cuddihy of Caltech and Paul Willis of Springborn Laboratories for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 51 on the TSP Request Card.*

NPO-16552

Heat- and Radiation-Resistant Lubricants for Metals

Protective and lubricating coatings are formed in situ.

NASA's Jet Propulsion Laboratory, Pasadena, California

A class of high-performance lubricants is under investigation at NASA's Jet Propulsion Laboratory. These lubricants are useful as additives to oils and greases in gears, transmissions, motors, and other machines where rubbing loads between metal parts may be severe. Because of their low volatility and lack of requirement for air or moisture, these lubricants should also be useful in vacuums.

One type of additive includes orthophthalonitrile and its derivatives. The additive would ordinarily be dissolved or suspended in a base fluid. Under high mechanical loads that cause lubricating fluid films to become thin, metal parts rub together. The orthophthalonitrile reacts with metal-surface asperities at high frictional temperatures to form lubricating films of metal phthalocyanine. These compounds are also formed with the hot metal fragments torn from the asperities. Bearing surfaces are thereby better protected from scoring, and fragments are rendered less harmful to the base fluids.

On heating to 250 to 260 °C, the additive also forms metal-free phthalocyanine, which is extremely thermally stable and an efficient lubricant. The phthalocyanine molecular structure is planar like that of graphite. However, it is even more effective than graphite as a lubricant because metal-free phthalocyanine can form extremely stable bonds to metal. At high temperatures in air, it does not form corrosive compounds as does molybdenum disulfide.

Without modification, orthophthalonitrile is not a suitable additive to conventional motor oils because of its low solubility in aliphatic compounds. One way of making soluble additives is to synthesize orthodinitriles substituted with aliphatic groups. Other potential substituents are cyclohexanes, linear polyethers, and fluorocompounds.

Very little of the precursor compounds to the formed solid pthalocyanine lubricant is needed. Moreover, since the additives can probably be synthesized from inexpensive materials, their low cost and high performance should make them suitable for commercial use.

Other chelating/lubricating additives are under consideration. Molecules can be tailored to confer solubility on the additives. Candidate molecular groups includes pyridino, sulfhydro, pyrrole, phenoyl, cyano, indolino, amino, keto, diketo, nitroso, hydroxylamino, thiophene, and carboxyl.

This work was done by Emil A. Lawton of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 108 on the TSP Request Card. NPO-16341*

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Fundamentals of Alloy Solidification

The potential benefits of microgravity processing are discussed.

A symposium was held at the Lewis Research Center in September of 1984. It dealt with the subject of microgravity and some basic metallurgical factors involved in the production of metals. General metallurgical areas of interest were metal solidification and processing. The five specific areas covered included (1) the undercooling of liquids, (2) porosity, (3) microstructure, (4) solidification, and (5) segregation.

Metallurgy today is characterized by processes that have evolved over the years in the unit gravity of Earth. Future processing will not be confined to Earth and may take place in a low or microgravity environment such as might be found on satellites, Space Shuttle-type vehicles, or a future space station. Because of this new access to a space environment, renewed interest is being generated in the role of gravity on basic metallurgical phenomena.

Fourteen individual papers were presented at this symposium entitled "Fundamentals of Alloy Solidification Applied to Industrial Processes." The authors represented material experts in government, academia, and industry. The underlying theme of this symposium was the possible benefits of microgravity processing and its beneficial effects on industry processing. Information contained in the conference publication is of such a nature that it would readily lend itself to inclusion in educational programs at the college level.

This work was done by F. Harf of **Lewis Research Center.** *Further information may be found in NASA CP-2337 [N84-34589/NSP], "Fundamentals of Alloy Solidification Applied to Industrial Processes," [$17.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14229

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Composite Refractory Felt/Ceramic Material

Ceramic protective coatings on combustor liners should adhere better.

Advanced commercial and military gas-turbine engines may operate at combustor-outlet temperatures in excess of 3,000° F (1,920 K). At these temperatures, combustor liners experience extreme convective and radiative heat fluxes. The ability of a plasma-sprayed ceramic coating to reduce liner-metal temperatures has been recognized. However, the brittleness of the ceramic layer and the difference in thermal expansion with the metal substrate have caused cracking, spalling, and some separation of the ceramic coating. Research originally directed at turbine-tip seals (or shrouds) has shown the advantage of applying the ceramic to a compliant metal pad such as FELTMETAL® (or equivalent).

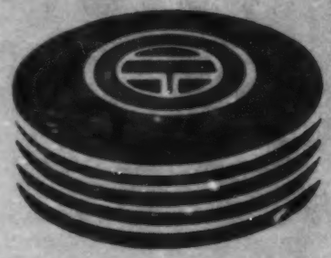
A report discloses the results of recent combustor-liner research where thick yttria-stabilized zirconia ceramic was plasma-sprayed on BRUNSBOND® substrates and exposed to nearly stoichiometric combustion. The compliant layer is a Hoskins Alloy 875 BRUNSBOND® (or equivalent) pad, 0.100 in. (0.25 cm) thick and 35 percent dense, brazed to an Inconel Alloy 718 (or equivalent) sheet 0.030 in. (0.08 cm) thick, using a high-temperature nickel-base braze compatible with both the felt and the backing. After brazing, all specimens were alumina-grit blasted immediately prior to application of a bond coat. All specimens were plasma-sprayed with a $Ni_{16.2}/Cr_{5.5}/Al_{0.6}/Y$ bond coat 0.003 to 0.005 in. (0.008 to 0.013 cm) thick. Specimens were then plasma-sprayed with an yttria-stabilized zirconia ceramic 0.008 or 0.013 in. (0.19 or 0.33 mm) thick.

Combustor screening tests exposed 30 test specimens to nearly-stoichiometric flame temperatures of 3,450° F (2,170 K) for 4 cycles. After completion of the screening tests, all 30 specimens showed no visible evidence of discoloration or failure. There were no mudflat cracks, felt/ceramic, or backing/felt separations on any of the panels.

Two panels were then chosen for endurance testing. These two specimens were exposed to the same conditions listed above but for 30 cycles. This repeated thermal cycling produced nonlinking, noncatastrophic mudflat cracks in the ceramic coating of one test specimen and caused partial ceramic separation from the felt pad in the other specimen.

This work was done by David B. Ercegovic, Curtis L. Walker, and Carl T. Norgren of **Lewis Research Center.** *Further information may be found in NASA TM-83490 [N84-14145/NSP], "Ceramic Composite Liner Material for Gas Turbine Combustors." [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14238

Computer Programs



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Materials

Intraply Hybrid Composite Design

Several theoretical approaches are combined in this program.

Intraply hybrid composites have been investigated theoretically and experimentally at Lewis Research Center over the past several years. Theories developed during these investigations and corroborated by attendant experiments were used to develop a computer program identified as INHYD (Intraply Hybrid Composite Design). INHYD includes several composites micromechanics theories, intraply hybrid composite theories, and an integrated hygrothermomechanical theory. Equations from these theories are used by the program as appropriate for the user's specific applications.

The theories embedded in INHYD are summarized in a recent NASA publication (NASA TM 82593). Instructions for using the program are outlined in a recently-completed User's Manual. The User's Manual provides step-by-step instructions for using INHYD, in both the interactive and the batch modes. INHYD has considerable flexibility and capability that the user can exercise through the several options described in the User's Manual.

Initially the manual presents test cases for the interactive mode, first for a dry, room temperature case and then for a case with moisture present. Then an interactive case is presented wherein the data are preentered, as they would be for a batch case. Next several cases for using INHYD in the batch mode are described. After following through the test cases presented, a user should be able to use INHYD either in the interactive or batch mode and with or without temperature and moisture effects to predict properties for uniaxial intraply hybrid composites.

The User's Manual also includes Appendices with: (1) a list of elements and subroutines in INHYD, (2) a list of symbols used in the program, and (3) a copy of the NASA TM 82593 where the theory in INHYD is summarized. It is planned to make INHYD available for public release through COSMIC.

This program was written by C. C. Chamis and J. H. Sinclair of **Lewis Research Center.** *For further information, Circle 28 on the TSP Request Card.*
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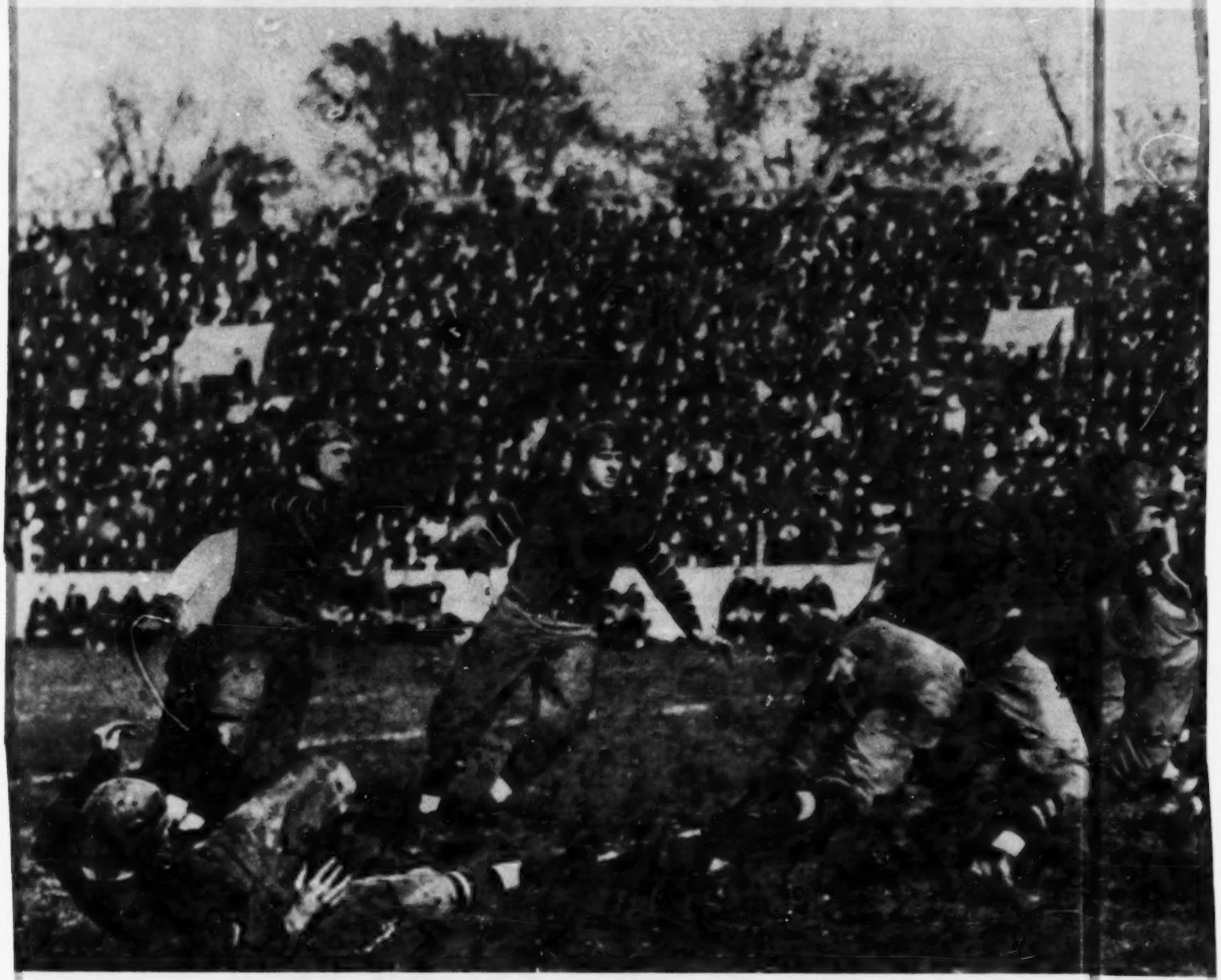

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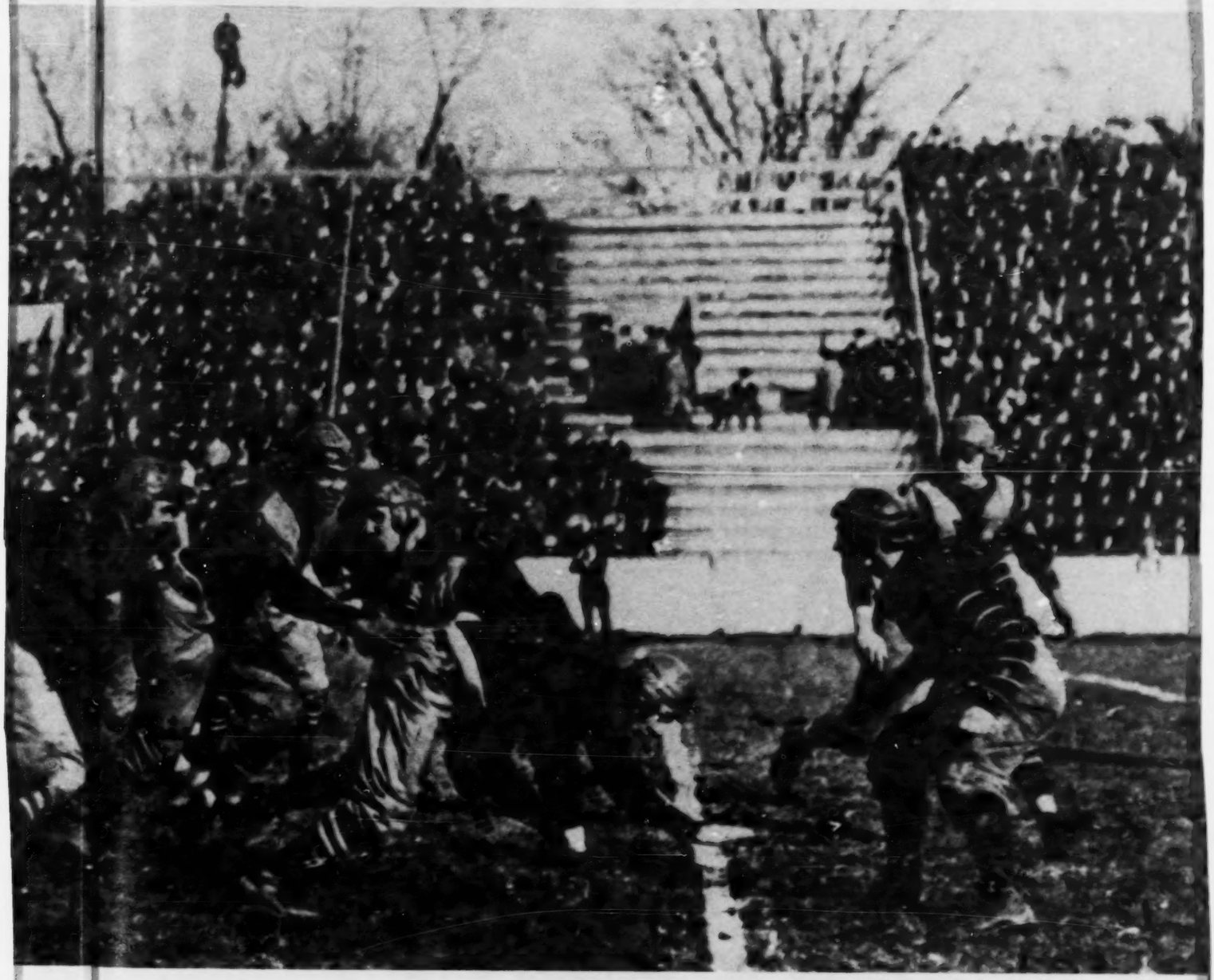

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Mechanics

Analyzing Static Loading of Complex Structures

Critical loading conditions are determined from the analysis of each structural element.

The Automated Thrust Structures Loads and Stresses (ATLAS) system is a series of programs developed to analyze the elements of a complex structure under static-loading conditions. ATLAS calculates internal loads, beam-bending loads, column- and web-buckling loads, beam and panel stresses, and beam-corner stresses.

ATLAS determines the most critical loading conditions from the analysis of each element. This eliminates the traditional approach of preselecting a limited number of conditions that are arbitrarily designated as critical before analysis. Although written for investigation of the Space Shuttle orbiter fuselage assembly, ATLAS could be adapted for such other complex structures as tall buildings, offshore oil rigs, and aircraft.

There are four main programs: (1) CONDENSE reformats and condenses input data obtained from the Monte Carlo flight tapes containing data on engine thrust, pitch, yaw, and other flight measurements; (2) FILTER significantly reduces the number of conditions to be processed, yet retains the critical load cases that meet selected criteria; (3) GLOBAL calculates the loads on the actuator and gimbal bearings due to engine thrust; and (4) ATLAS sums the loads due to thrust, pitch, yaw, and inertia.

The five extreme positive and negative values are listed for the following: (a) shear panel loads (trim3 and quam4 components), (b) beam-corner stresses, (c) beam-element webbing loads, and (d) axial strut loads. The margins of safety for beam-element webbings and struts are also calculated.

These programs are written in FORTRAN IV and Assembler for batch execution and have been implemented on an IBM 370-series computer with a central-memory requirement of approximately 2,200K of 8-bit bytes for the maximum number of elements (150 trim3, 75 quam4, 450 corners, 150 webs, and 100 struts). Fewer elements require less core. ATLAS was developed in 1983.

The programs were written by Darrell C. Gallear of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 29 on the TSP Request Card.*
MSC-20896

Shadowed Space Heating of Sparse Structures

Complete heat-flux and temperature maps can be computed.

A computer program SSQ has been developed to address and quantify the complex, solar-shadowing conditions inherent in sparse, lattice-type space structures. The analysis procedure is one of assessing partial shadowing of structural elements by multiple, similar slender members. The program yields schedules of incident-solar, Earth-thermal, and Earth-albedo radiation throughout a complete orbit for elemental locations on selected structural members. Thermal response can be computed in an optional routine. Complete heat-flux and temperature mapping can be obtained by repeated computations for selected elements of interest.

Thermal analysis of relatively sparse structures in the space environment has customarily omitted the consideration of shadowing by up-Sun structural members. This convention has been frequently questioned in the case of lattice-type structures supporting very large, near-planar, Earth-facing surfaces (e.g., antennas). For these, significant shadowing can occur whenever the solar vector is nearly tangent to the orbital path. It thus becomes advisable to quantify the shadowing effect, but sparse structures present an exceptional element of complexity.

Space-heating analysis procedures usually assume either total shadowing or total solar irradiation of individual elemental areas of mapped surfaces. While the latter convention is reasonably sound for structural assemblies of which most or all geometric dimensions are of the same order of magnitude, it is less realistic for sparse structures composed of slender members having extremely-high length-to-diameter (L/d) ratios. In such cases, multiple up-Sun (i.e., shadowing) members may yield only partial shadowing of an elemental area of interest, with the degree and duration of shadowing being a strong function of the size and density of the structural assembly. No prior analysis procedure addressing this problem is known to have been developed.

The SSQ program permits the definition of numbered structural-node locations in the spacecraft coordinate system, followed by the definition of line segments (structural members) in terms of bounding-node numbers. Slender structural members are assumed to be cylindrical and are assigned values of diameter, thermal mass per unit of length, solar absorptance, emittance, and view factor to space. Partially or totally opaque bodies are also defined in terms of bounding-line segments, and the latter surfaces are assigned transmissivities that may vary as functions of solar angle of incidence.

The SSQ program heat-flux output can easily be formatted as required for input to other thermal-analysis programs. Temperature output can also be formatted to accommodate the input requirements of structural-analysis programs.

This program was written by R. F. O'Neill and J. L. Zich of General Dynamics Corp. for **Lewis Research Center.** *For further information, Circle 117 on the TSP Request Card.*
LEW-13977

Rendezvous BET Program

It computes the relative positions of two vehicles in concentric orbits.

The LRBET3 program is a best-estimate-of-trajectory (BET) calculation for postflight trajectory analysis of Shuttle orbital rendezvous maneuvers. LRBET3 produces estimated measurements for reconstructing relative positions of two vehicles in approximately concentric orbits based on tracking data from one or both vehicles. A Kalman filter and a smoothing filter are applied to the relative measurement input data to estimate the state vector, reduce noise, and produce the BET output. The BET calculation minimizes the variances of all the trajectory estimation errors.

LRBET3 incorporates a Kalman filter to process all rendezvous measurement data prior to a given time. This output is then used by a backward-smoothing filter to make a state vector based on relative tracking data before and after the given time. The normal LRBET3 output is the state vector from the smoothing filter. Abbreviated runs can be performed to check data quality using only the forward Kalman filter. The state vector is propagated every fourth time episode, with the nominal time interval being 0.96 second.

LRBET3 is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 76K (octal) of 60-bit words. The program was written in 1982.

This program was written by William Murphey Lear of TRW, Inc., for **Johnson Space Center.** *For further information, Circle 14 on the TSP Request Card.*
MSC-20785

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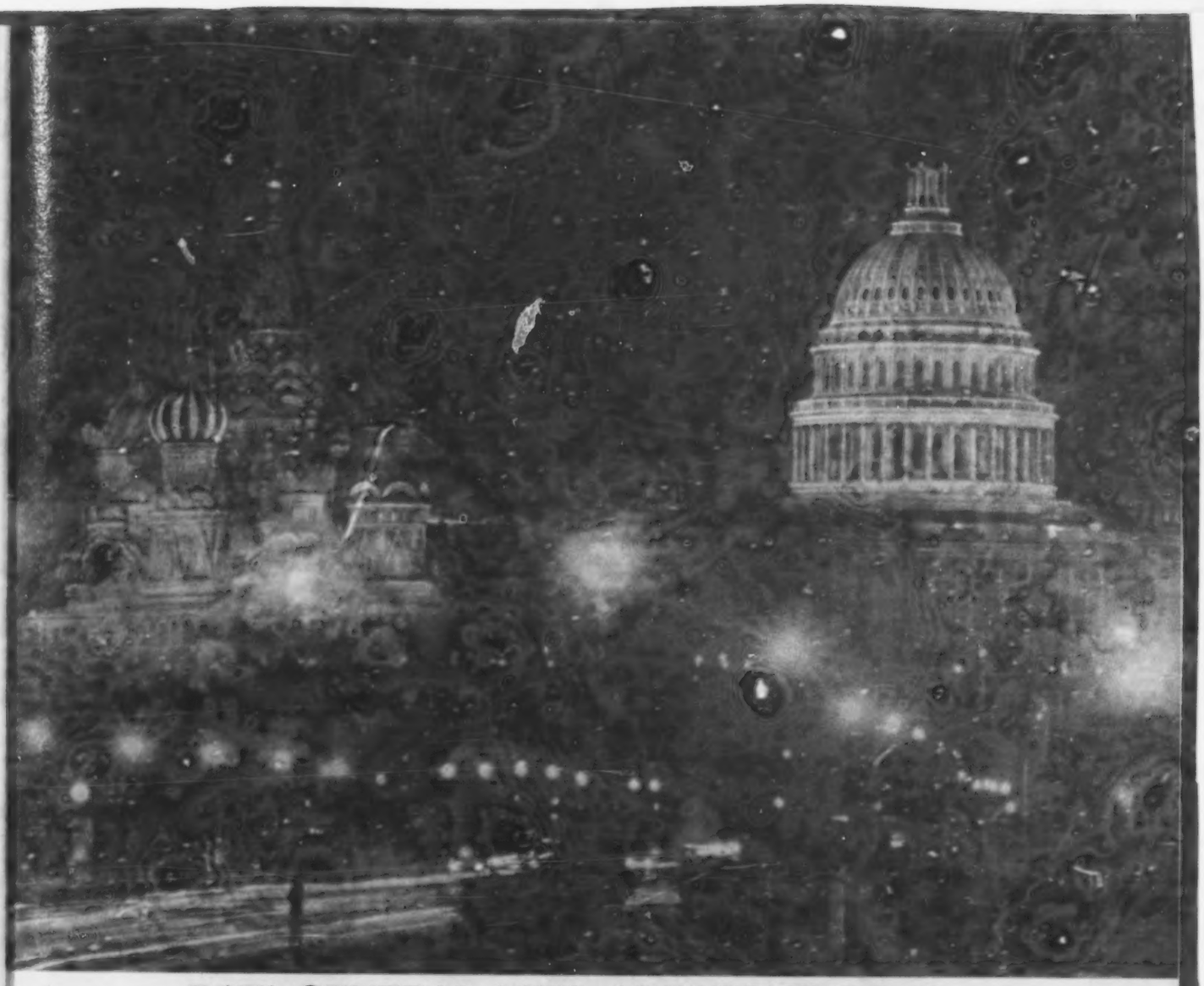

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Circle Reader Action No. 353

Variable-Conductance Heat Pipes

It calculates the length of the gas-blocked region and the vapor temperature in the active portion.

In response to a need to accurately and efficiently predict the performance of variable-conductance heat pipes (VCHP's) incorporated in spacecraft thermal-control systems, a computer code VCHPDA has been developed to interact with thermal analyzer programs such as SINDA (Systems Improved Numerical Differencing Analyzer). Given the axial temperature distribution and design specifications of the VCHP, the code is used to calculate the length of the gas-blocked region and the vapor temperature in the active portion of the heat pipe from the simultaneous solution of nonlinear, coupled integro-differential equations governing conservation of noncondensible gas species and thermal energy based on the "flat gas-front" theory.

Historically, the code originated in efforts carried out under the Advanced Thermal Control Experiment program, during which a method to analytically simulate a gas-loaded, variable-conductance heat pipe was developed. A computer subroutine VCHP2 was implemented to numerically solve the analytical model. The VCHP2 code, which interfaced with general thermal models involving heat pipes, was used successfully in steady-state thermal simulation of systems such as the transmitter experiment package (TEP) variable conductance heat pipe system (VCHPS) on the Canadian Communications Technology Satellite (CTS) *Hermes*. Subsequent attempts, however, to utilize VCHP2 for transient thermal analyses yielded unsuccessful results due to numerical instabilities arising during the gas/vapor front-location/vapor-temperature calculations.

As part of efforts to investigate several thermal anomalies that occurred during operation of the CTS spacecraft, the solution scheme in VCHP2 was analyzed in order to uncover the source of the numerical problems. The analysis revealed that the iterative approach used in the subroutine to obtain a convergent solution (starting from an initial, guessed gas length and vapor temperature) was inadequate in view of the nonlinear nature of the model. A new analytical method was formulated which, under most physically realizable operating modes, unconditionally circumvents numerical instabilities.

In addition, two new features were introduced into the VCHP model that permit simulation of the effects of an ice-plug formation and open-artery capacity on the performance of a VCHP system. The appropriate logic for solution of the analytical model was incorporated into the revised version of the VCHP2 subroutine, now called VCHPDA.

The advantages of the VCHPDA code over prior programs are the improved accuracy, unconditional stability, and increased efficiency of the solution resulting from the novel approach and the use of the state-of-the-art numerical techniques for solving the VCHP mathematical model.

The code is a valuable tool in the design and evaluation of advanced thermal-control systems using variable-conductance heat pipes. It is written in FORTRAN IV for use on CDC 600 computers.

This program was written by David Antoniuk of TRW, Inc. for **Lewis Research Center.** *For further information, Circle 7 on the TSP Request Card.*
LEW-14075

Programing Structural Synthesis System

This program aids research in analysis and optimization.

The Programing Structural Synthesis System (PROSSS2) was developed to provide a structural-synthesis capability by combining access to SPAR with the CONMIN program and a set of interface procedures. SPAR is a large general-purpose finite-element structural-analysis program, and CONMIN is a large general-purpose optimization program.

The implementation of the PROSSS2 analysis/optimization process results in a minimized objective function, typically the mass defined in terms of a set of such design variables as the cross-sectional dimensions of a structural member. Also, the member is subject to a set of constraints; for example, the stress must be less than some allowable value.

PROSSS2 is intended to be used in the following three basic ways: (1) as a research tool for the development of optimization techniques that will interface with an efficient analysis program, (2) as a research tool for testing new analysis techniques that will interface with an efficient optimization program, and (3) as an application tool that can be adapted to a wide range of different problems.

With PROSSS2, the analysis and optimization programs are executed repeatedly in a looping manner until the process is stopped by a user-defined termination criteria. This part of the system is referred to as the repeatable part of PROSSS2. However, some of the analysis, such as model definition, need be done only once and can be saved for future use. These parts are performed outside the loop and are referred to as the nonrepeatable part of PROSSS2. Three options are provided for organizing optimization procedures by combining nonlinear or piecewise-linear programing methods with analytic or finite-difference gradients.

In this newest release, PROSSS2 is controlled by SPAR run streams instead of by the control language of the computer. This is accomplished by integration of the entire PROSSS2 program as new processors within the SPAR program. The user supplies PROSSS2 with problem-dependent routines that express the relationships between the structural parameters of interest in SPAR and the design variables used in CONMIN.

PROSSS2 is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER-series computer. However, the code is machine-independent and can be run with any computer on which SPAR has been implemented. The implementation of PROSSS2 on the CDC requires approximately 51K (octal) of 60-bit words. The PROSSS2 user must have access to the SPAR program. PROSSS2 was developed in 1984.

This program was written by James L. Rogers, Jr., of **Langley Research Center.** *For further information, Circle 72 on the TSP Request Card.*
LAR-13408

Vibration-Response Analysis

The dynamic behaviors of structures are analyzed interactively.

An interactive steady-state vibration-response program, VIBRA, has been developed. Frequency-response analyses are commonly used in evaluating the dynamic behaviors of structures subjected to cyclic external forces. VIBRA calculates the frequency response using a modal-superposition approach. This method is applicable to single or multiple forces applied to a linear, proportionally damped structure in which the damping may be viscous or structural.

VIBRA computes the forced-acceleration response at any selected point on the structure for a given vibratory loading. VIBRA provides tabular output with optional plots of response versus frequency. The interactive capability enables rapid evaluation of the structural response.

VIBRA requires the input of modal data from only the selected response and applied-vibratory-load points. These data may be obtained either from ground vibration measurements or from a natural vibration analysis. VIBRA can use results from any vibration analysis that has out-

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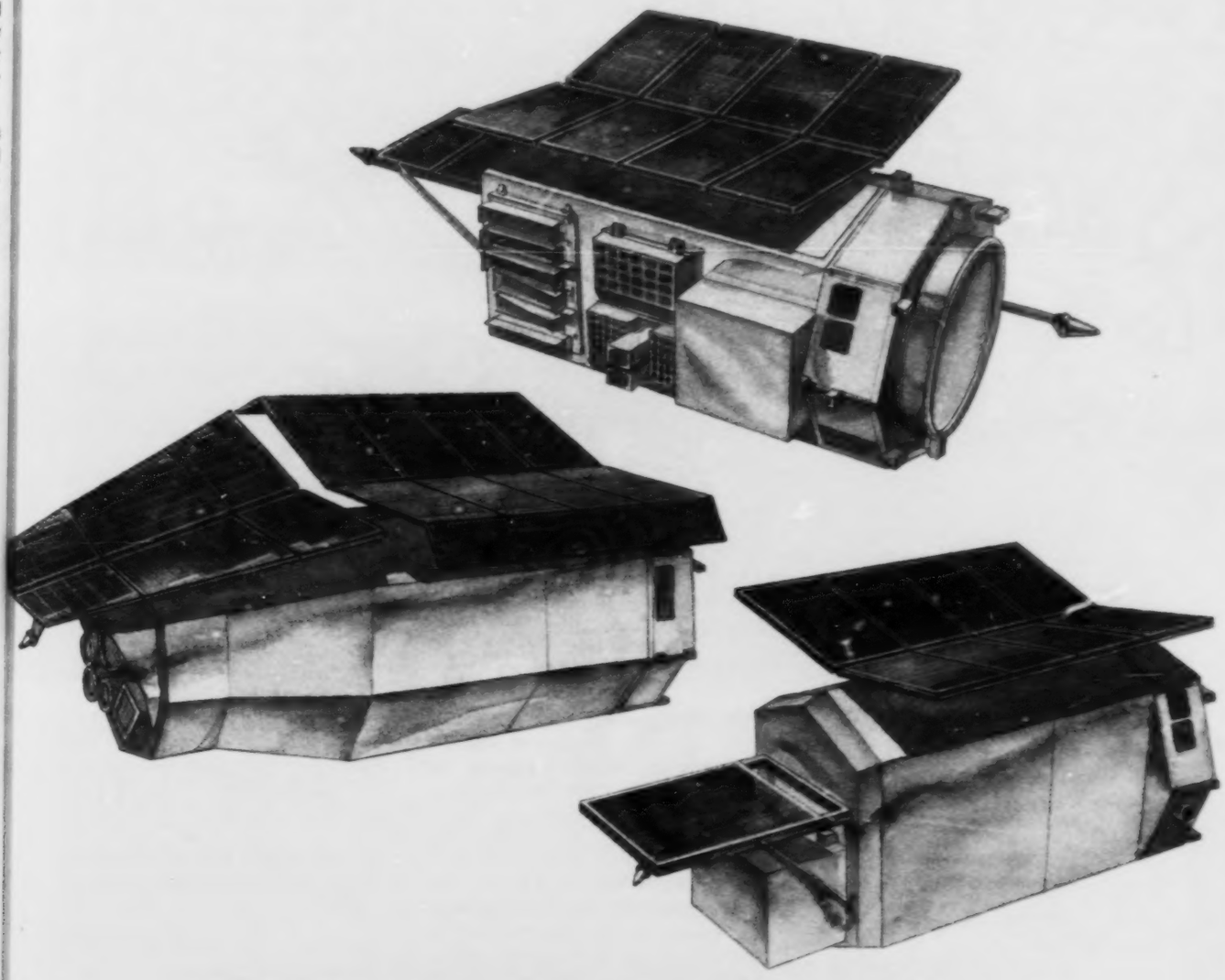

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put in the form of generalized masses, eigenvalues, and eigenvectors. Thus, VIBRA can be used as a postprocessor for such finite-element codes as NASTRAN.

The user specifies a starting frequency, ending frequency, and frequency step for the VIBRA response analysis. VIBRA output can be plotted on the screen as real acceleration versus forcing frequency, imaginary acceleration versus forcing frequency, acceleration amplitude versus forcing frequency, and phase angle versus forcing frequency. The interactive graphics user has a zoom facility available for detailed examination of the plots. Optionally, the response data are stored for later use.

VIBRA is written in FORTRAN 77 for interactive execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of 120K (octal) of 60-bit words. The graphic output requires the Plot-10 plotting package. The VIBRA program was developed in 1984.

This program was written by Lynn M. Bowman of the U.S. Army Aviation Systems Command for **Langley Research Center.** *For further information, Circle 74 on the TSP Request Card.*
LAR-13291

Fatigue-Crack-Growth Structural Analysis

Elastic and plastic deformations are calculated under a variety of loading conditions.

The prediction of fatigue-crack-growth lives can be made with the Fatigue-Crack-Growth Structural Analysis (FASTRAN) computer program. As cyclic loads are applied to an initial crack configuration, FASTRAN predicts crack length and other parameters until a complete break occurs. The loads may be tensile or compressive and of variable or constant amplitude. FASTRAN incorporates linear-elastic fracture mechanics with modifications for load-interaction effects caused by crack closure. FASTRAN is considered a research tool, because of lengthy calculation times.

Surface cracks, surface cracks at holes, and corner cracks at holes in a three-dimensional body can be modeled. The representation is based on the Dugdale model, with alterations to allow plastically deformed material along crack surfaces as the crack advances. Plane stress and plane strain conditions are simulated in FASTRAN by using a constraint factor on tensile yielding to account for three-dimensional effects. FASTRAN has successfully predicted crack growth in metallic-alloy sheet materials under aircraft-spectrum loading.

FASTRAN is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer under NOS 1.4 with a central-memory requirement of approximately 200K (octal) of 60-bit words. The program was developed in 1981.

This program was written by J. C. Newman, Jr., of **Langley Research Center.** *For further information, Circle 101 on the TSP Request Card.*
LAR-13412

Machinery

Aircraft Takeoff and Landing Analysis

The behavior of a flexible or rigid aircraft is simulated under a variety of conditions.

The Active Gear, Flexible Aircraft Takeoff and Landing Analysis program, AGFATL, completely simulates aircraft takeoff and landing dynamics. AGFATL represents an airplane either as a rigid body with six degrees of freedom or as a flexible body with multiple degrees of freedom.

The airframe flexibility is represented by the superposition of up to 20 free vibration modes on the rigid-body motions. The analysis includes maneuver logic and autopilots programed to control the aircraft during the glide slope, flare, landing, and takeoff. The program is modular so that the performance of the aircraft in flight and during landing and ground maneuvers can be studied separately or in combination. A program-restart capability is included in AGFATL.

Eleven effects simulated in the program include the following:

1. Flexible aircraft control and performance during glide slope, flare, landing roll, and takeoff roll under conditions of changing winds, engine failures, brake failures, control-system failures, strut failures, restrictions due to runway length, and control-variable limits and timelags;
2. Landing-gear loads and dynamics for up to five gears;
3. Single and multiple engines (maximum of four), including selective engine reversing and failure;
4. Drag-chute and spoiler effects;
5. Wheel braking (including skid control) and selective brake failure;
6. Aerodynamic ground effects;
7. Aircraft-carrier operations;
8. Inclined runways and runway perturbations;
9. Flexible or rigid airframes;
10. Rudder and nose-gear steering; and
11. Actively-controlled landing-gear shock struts.

The input to AGFATL includes data that describe runway roughness; vehicle geometry, flexibility and aerodynamic characteristics; landing gear(s); propulsion; and such initial conditions as attitude, attitude-change rates, and velocities. AGFATL performs a time integration of the equations of motion and produces comprehensive information on the airframe, state-of-maneuver logic, autopilots, control response, and aircraft loads from impact, runway rollout, and ground operations. Flexible-body and total (elastic plus rigid-body) displacements, velocities, and accelerations are also produced in the flexible-body option for up to 20 points on the aircraft.

AGFATL is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with an overlaid central-memory requirement of approximately 141K (octal) of 60-bit words. The program was last updated in 1984.

This program was written by John R. McGehee of **Langley Research Center.** *For further information, Circle 80 on the TSP Request Card.*
LAR-13390

Nonconical Relaxation for Supersonic Potential Flow

Nonlinear, three-dimensional effects are computed from the full potential-flow equation.

The Nonconical Relaxation program, NCOREL, employs a new computational technique for the prediction of inviscid, nonlinear supersonic aerodynamics. Unlike conventional linear potential equations, NCOREL utilizes the full potential-flow equation to predict the formation of supercritical crossflow regions, embedded shocks, and bow shocks.

The embedded shocks are of great importance to design engineers because these features can significantly alter wing characteristics at low-to-moderate supersonic speeds. Nonlinear effects are also important on wings that have supersonic leading edges or bodies that have slopes greater than the mach angle.

NCOREL has been applied successfully to a wide variety of body and wing configurations in the mach-number range from 1.5 to 3. With NCOREL, the aerodynamicist can reliably predict the detailed

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40,000	351.50	99.71	13.13	6.38	9.07
Float Benchmark					
40,000	11.46	17.71	.83	.50	.80

Unix Benchmarks

	DSI-32	VAX 780	VAX 750
O.S. Overhead	3.88	4.4	7.0
C Compiler Test	.55	1.0	1.7
Sieve of Eratosthenes	1.93	1.7	2.4

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Circle Reader Action No. 440

spanwise behavior of realistic three-dimensional supersonic wings and bodies in high-lift maneuvers.

The approach used by NCOREL consists of solving the nonconservative finite-difference analog of the full potential equation in a spherical coordinate system. Conformal mappings are used to generate a grid in the spherical crossflow plane capable of resolving large gradients in the vicinity of the leading edge.

NCOREL computes a conical flow at the apex of the coordinate system and uses an implicit marching technique to obtain three-dimensional crossflow solutions. Relaxation techniques for supersonic and subsonic regimes form the basis for the crossflow-plane solutions. The numerical technique allows for the capture of both embedded crossflow and bow-type shocks. In addition, the bow shock can be fitted and used as the crossflow-plane outer boundary.

There are several input geometry options built into NCOREL, including the Harris wave-drag input format. Isolated-wing or isolated-body cross sections are usually considered, but wing/body cross sections can be input if the necessary mesh resolution is available. NCOREL calculates moments, areas, forces, lift and drag coefficients, and coordinates of shocks and crossflows.

NCOREL is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of 310K (octal) of 60-bit words. This program was developed in 1983.

This program was written by Michael J. Siclari of Grumman Aerospace Corp. for **Langley Research Center.** *For further information, Circle 76 on the TSP Request Card.*
LAR-13346

Analysis of Lubricant Jet Flow

A computer program helps assure adequate pinion lubrication.

A computer program, IMPOUT 2, has been developed using newly-established "limit formulas" to prevent lubricant nonimpingement on the pinion. The standard nozzle orientation usually found in gear-sets where the offset is zero and the inclination angle is zero will often cause the pinion to be deprived of preliminary impingement. This can be an important cause of incipient scoring failure in high-speed drives. This work is an extension of a previous study that was limited to standard centers and tooth proportions only. This work includes long and short addenda and modified center distances.

The analysis developed the equations for the limit values of variables necessary to remove prior severe limitations or constraints necessary to facilitate the computer analysis. Results of an analysis determined that (a) the industrial standard nozzle orientation with an offset S = 0 and inclination angle B = 0 will often cause the pinion to be deprived of primary impingement, which can be an important cause of incipient gearing failure in high-speed drives; (b) for ratios larger than 1:1, the oil jet will impinge on the gear teeth only, unless a minimum calculated jet velocity is provided to lubricate the pinion teeth; (c) when a minimum jet velocity is provided, the oil-jet offset must be equal to or greater than a minimum calculated offset to assure impingement on the pinion; and (d) as the oil-jet velocity is increased above this calculated minimum value, the impingement depth will increase but at a decreasing rate. The maximum impingement depth will generally not exceed 10 percent of the tooth profile depth.

The IMPOUT 2 program is written in ANSI FORTRAN IV for use on a CDC 750. The computer program can be used to analyze impingement depth on the gear teeth for an oil jet located at the out-of-mesh position with arbitrary offset and inclination angles and with arbitrary addendum and center-distance modification.

This work was done by Dennis P. Townsend of **Lewis Research Center** *and Lee S. Akin of California State University at Long Beach. Further information may be found in NASA TM-83723 [N84-29224/NSP], "Lubricant Jet Flow Phenomena in Spur and Helical Gears with Modified Center Distances and/or Addendums — for Out-of-Mesh Conditions" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14242

Aerodynamic Characteristics of NACA 16-Series Airfoils

Standard data from the literature are incorporated into the program.

A comprehensive and easily-accessible data bank of the aerodynamic characteristics of NACA 16-series airfoils is incorporated into the AIRFOIL program for use in propeller performance research. The low-drag, high-critical-speed airfoils could be effective in advanced turboprop designs currently under investigation.

Until AIRFOIL, aerodynamic characteristics were available for only a small range of cambers, thicknesses, angles-of-attack, and mach numbers. AIRFOIL incorporates digitized data from standard curves in the literature and interpolates between thickness ratios and design-lift coefficients. Linear extrapolation is used to obtain data from each set of mach numbers, angles-of-attack, and lift coefficients beyond those previously available. Additional calculations are included to account for the nonlinear behavior of lift and drag coefficients beyond the stall angle.

The AIRFOIL performance mode requires an angle-of-attack, a mach number, and a geometry as input, while the design mode requires a design-lift coefficient, a mach number, and a geometry. Both modes compute the drag coefficient and lift-to-drag ratio. AIRFOIL can be used for sections with lift coefficients up to 0.8, thickness ratios from 4 to 21 percent, mach numbers from 0.3 to 1.6, and angles-of-attack from −4° to 8°. AIRFOIL gives reasonable results when compared to wind-tunnel data.

AIRFOIL is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 137K (octal) of 60-bit words. The program was developed in 1983.

This program was written by Catherine M. Maksymiuk of **Langley Research Center** *and Sally A. Watson Viken of the University of Kansas Center for Research, Inc. For further information, Circle 77 on the TSP Request Card.*
LAR-13355

Wall Interference in Two-Dimensional Wind Tunnels

Viscosity and tunnel-wall constraints are introduced via boundary conditions.

The TWINTN4 computer program was developed to implement a method of posttest assessment of wall interference in two-dimensional wind tunnels. Classical methods for evaluating wind-tunnel wall interference are generally unsatisfactory for use with wind tunnels for two major reasons: (1) It has not been possible to define the boundary conditions for slotted or perforated walls with the required generality and accuracy, and (2) the principle of linear superposition on which the classical approach is based becomes invalid at transonic speeds. The method used by TWINTN4 involves the successive solution of the transonic small-disturbance potential equation to

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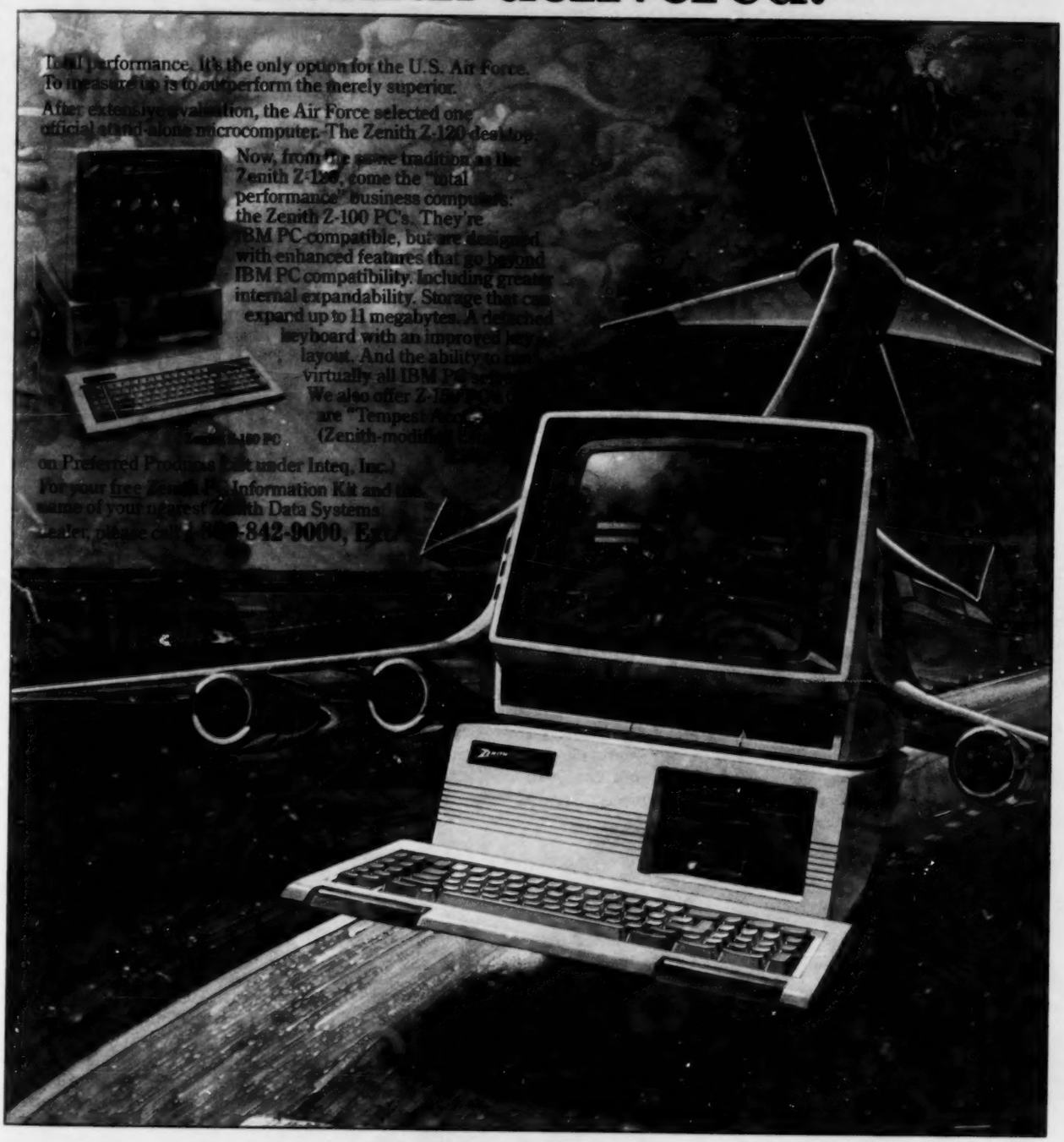
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Circle Reader Action No. 349

calculate the wind-tunnel flow, the perturbation attributable to the model, and the equivalent free airflow around the model.

The total procedure employed by TWINTN4 can be considered as a nonlinear counterpart of classical wall-interference theory, with the effects of both viscosity and tunnel-wall constraints being introduced through experimentally-measured boundary conditions. These boundary conditions are developed from pressure-distribution measurements made on the model and the tunnel walls.

The wall-induced perturbation field is taken as the difference between the model perturbation and the total perturbation in the tunnel flow solution. A correction for the angle-of-attack and the corrected far-field mach number are determined during the equivalent free-air solution. The influence of nonuniformities in the wall-induced velocity field is determined by comparing the equivalent free-air pressure distribution with the experimental distribution adjusted to the new reference mach number.

TWINTN4 offers two methods for combining sidewall boundary-layer effects with upper and lower wall interference. In the sequential procedure, the Sewall method is used to define a flow free of sidewall effects, which is then assessed for upper and lower wall effects. In the unified procedure, the wind-tunnel flow equations are altered to incorporate effects from all four walls at once.

The TWINTN4 program is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 175 computer with a central-memory requirement of approximately 47K (octal) of 60-bit words. This program was developed in 1977 with refinements added in 1984.

This program was written by William B. Kemp, Jr., of Virginia Associated Research Campus for **Langley Research Center.** *For further information, Circle 81 on the TSP Request Card.*
LAR-13394

Predicting Vortex Shedding in Supersonic Flow

Nonlinear aerodynamic characteristics of missile bodies are computed.

The program NOZVTX calculates the nonlinear aerodynamic characteristics and flow fields of missile bodies at various angles-of-attack and roll in supersonic flow. At high angles-of-attack, boundary-layer fluids leave the body surface from separation points on both sides of the body and roll up into a symmetrical vortex pair on the lee side. The vortex-shedding characteristics are directly influenced by the body shape.

The vortex wake is modeled by tracking discrete vortexes in crossflow planes. NOZVTX reduces the three-dimensional steady flow around the body to a two-dimensional, unsteady, separated-flow system. The predicted vortex distributions and velocity components are in reasonable agreement with the actual measurements of flow characteristics about slender bodies of circular or noncircular cross section, for large angles-of-attack and moderate mach numbers.

NOZVTX models the airborne body by using a supersonic panel method for noncircular cross sections or an axisymmetric line source and doublets for circular cross sections. The vortex cloud in NOZVTX consists of many point vortexes, each represented by a viscous core. Pressure and vortex-trajectory calculations are carried out by the conformal mapping of any noncircular cross sections to a circle and using a full Bernoulli equation.

The surface pressure distribution on the body is used to calculate the forces on the body and the separation points. The user can specify vortex separation as either laminar or turbulent. The NOZVTX output includes (a) the geometry, centroids, and surface pressure of the source panels and (b) the positions, strengths, and velocity components of the shed vortexes.

NOZVTX is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 231K of 60-bit words. This program was developed in 1983.

This program was written by M. R. Mendenhall and S. C. Perkins, Jr., of Nielsen Engineering and Research, Inc., for **Langley Research Center.** *For further information, Circle 79 on the TSP Request Card.*
LAR-13375

Predicting Wall Modifications for Adaptive Wind Tunnels

The wall shape is changed iteratively until it matches the streamlines.

FLEXWAL predicts the upper and lower wall modifications necessary to remove wall-interference effects in adaptive-wall wind tunnels. FLEXWAL aids in the elimination of wall-interference effects on objects being tested in a typical two-dimensional wind tunnel with rigid sidewalls and flexible, solid floor and ceiling boundaries. The iterative procedure is valid for subsonic and transonic test conditions, and the convergence of the method has been verified both analytically and experimentally.

The flow field around a test article in a wind tunnel is constrained by the walls of the tunnel. FLEXWAL uses the Cauchy integral formula to extend the real internal flow field around the test article to infinite distance by solving for an imaginary flow outside the wind tunnel. These two flows are coupled at the wall boundary where modifications of the real internal flow are made until the external and internal flows match. Continuity occurs when the measured wall data match the calculated data.

The wall-shape correction is applied iteratively until the contour of the flexible wall matches the streamline of the flow about the model being tested. The required input includes the mach number, temperature, pressure, and wall-relaxation factors. The output contains the wall-position corrections required to match the flow-field contour.

FLEXWAL is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 52K (octal) of 60-bit words. This program was developed in 1981.

This program was written by Joel L. Everhart of **Langley Research Center.** *For further information, Circle 75 on the TSP Request Card.*
LAR-13301

Two Programs for Supersonic Wing Design and Analysis

Many useful parameters are calculated for design, analysis, and optimization.

COREL and W12SC3 are useful in the aerodynamic design and analysis of wings for supersonic speeds. Both programs were used in developing the Super Critical Conical Camber (SC3) concept, in which high supersonic lift coefficients are obtained efficiently by controlling crossflow development. The COREL (Conical Relaxation) program solves the nonlinear full potential equation for a spanwise section of a wing in the crossflow plane, and an option exists to correct the result for nonconical geometry. W12SC3 applies linear-theory panel methods to compute solutions for a wing/body configuration. The programs are restricted to supersonic flows and are useful for many design, analysis, and optimization applications.

COREL computes full potential solutions, including the nonlinear mixed subsonic/supersonic crossflow that develops on supersonic wings with high lift coefficients. The solution is obtained for a nonconservative form of the governing equations, and the bow and crossflow shocks are captured as part of the solution. An initial aerodynamic solution is obtained on a crude grid to estimate the bow-shock position; then a finer mesh is mapped, keeping the computed bow-shock location within the problem boundaries. The input geometry can be specifically defined or calculated in COREL using Craidon bicubic-spline patches.

W12SC3 combines source and vortex-panel-singularity distributions for calculating the linear-theory estimate of the configuration aerodynamics. The user can specify Woodward II calculations for arbitrary body models or Woodward I calculations for an interference shell that approximates the actual body shape. Carlson's nonlinear correction to the supersonic linear-theory wing pressures can be applied. If desired, COREL will produce conical-panel pressure data for further processing by W12SC3. W12SC3 can perform the following five aerodynamic functions: (1) full analysis, (2) full design, (3) full optimization, (4) mixed design/analysis, and (5) mixed design/optimization. Results from W12SC3 include the wing camber distribution, surface velocities, pressure coefficients, integrated forces and moments.

COREL and W12SC3 are written in FORTRAN IV for batch execution and have been implemented on a CDC CYBER 170-series computer with a central-memory requirement of 252K (octal) of 60-bit words. These programs were developed in 1983.

This program was written by William H. Mason, Bruce S. Rosen and Bernard Grossman of Grumman Aerospace Corp. for **Langley Research Center.** *For further information, Circle 71 on the TSP Request Card.*
LAR13239

Second-Order-Potential Analysis and Optimization

An optimum camber is designed for supersonic and hypersonic vehicles.

The Second Order Potential Analysis and Optimization (SOPA) package is a set of computer programs used to predict aerodynamic characteristics and to design optimum camber for both supersonic and hypersonic vehicles. The analysis program incorporates second-order-potential, small-disturbance theory for the analysis of wing/body configurations. The optimization program uses analysis results to generate optimum camber, twist, or flap deflections by minimizing zero suction drag.

Conventional aerodynamic linear panel methods have proved inexact, while finite-difference methods are computationally exorbitant. SOPA calculates a first-order linear solution, which is then used as input to a nonlinear Prandtl-Glauert approximation. The complete first-order solution is a linear combination of the crossflow solution, the camber solution, the lift due to thickness, and the lift due to the body. This second-order-potential approach accurately predicts airfoil- and cone-surface pressures.

Using SOPA, the user can perform first-order optimizations on configurations having up to 10 surfaces and 1 body. Second-order optimizations can be performed on planar configurations without a body. The input to SOPA consists of the body geometry, lifting-surface geometry, and various aerodynamic and numerical-control values. The geometry information may either be generated by the user or created by the APAS program [see "Aerodynamic Preliminary Analysis" on page 362 of *NASA Tech Briefs*, Vol. 5, No. 3, Fall 1980 (LAR-12404)]. SOPA output consists of pressure coefficients and aerodynamic coefficients.

SOPA is written in FORTRAN V for batch execution and has been implemented on a CDC CYBER 170-series computer under NOS 1.4 with a central-memory requirement of approximately 351K (octal) of 60-bit words. SOPA was developed in 1984.

This program was written by Willard C. Clever of Rockwell International Corp. for **Langley Research Center.** *For further information, Circle 49 on the TSP Request Card.*
LAR-13314

Mathematics and Information Sciences

Shaded-Color Picture Generation of Computer-Defined Arbitrary Shapes

Objects are displayed as smooth, color-shaded surfaces.

Many engineering applications require the development of geometric models of shapes for use in computational procedures. The best way for the engineer to verify a geometric model, and the numerical data it represents, is to look at a graphic display of the model. The graphic display must be as realistic as possible in order to provide the engineer with as much visual information as possible.

The SHADE computer program generates realistic color-shaded pictures from computer-defined arbitrary shapes. Objects that are defined for computer representation can be displayed as smooth, color-shaded surfaces, including varying degrees of transparency. SHADE-generated results can also be used for the presentation of computational results. By performing a color mapping, SHADE can color the model surface to display such analysis results as pressures, stresses, and temperatures. NASA has used SHADE extensively in the design and analysis of high-performance aircraft. Industry should find applications for SHADE in computer-aided design and computer-aided manufacturing.

Objects can be defined for SHADE in terms of polygons, PAN AIR networks, or parametric bicubic splined patches. The image data used to generate the picture consist of polygons. The parametric bicubic patch definition is subdivided to yield a polygonal definition for shaded display purposes. Defining polygons can have a different color associated with each corner point. SHADE offers numerous options including:

- Varying the resolution from 256 to 4,096 pixels,
- Displaying text with the graphics,
- Creating and editing a user view field,
- Controlling the shading techniques (i.e., transparency, highlights, and specular reflectivity, and
- Generating color bars for displayed results correlation.

SHADE is written in VAX FORTRAN and MACRO Assembler for either interactive or batch execution on a DEC VAX 11/780 operating under VMS. The memory requirements for the SHADE program are a function of the array sizes, which can be varied according to the user's needs. The program as currently configured requires 2.5 million bytes of memory. The program is written to generate graphics data files for the DICOMED D48 film plotter, but should be adaptable to any raster-scan graphics device. SHADE was developed in 1983.

This program was written by James V. Cozzolongo of **Ames Research Center** *and Dexter L. Hermstad and Daniel S. McCoy of Informatics General Corp. based on an original program written by James Clark of Silicon Graphics. For further information, Circle 115 on the TSP Request Card. ARC-11496*

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Quick-Connect Heavy-Duty Fastener

An attaching device combines fast connection and disconnection with high strength.

NASA's Jet Propulsion Laboratory, Pasadena, California

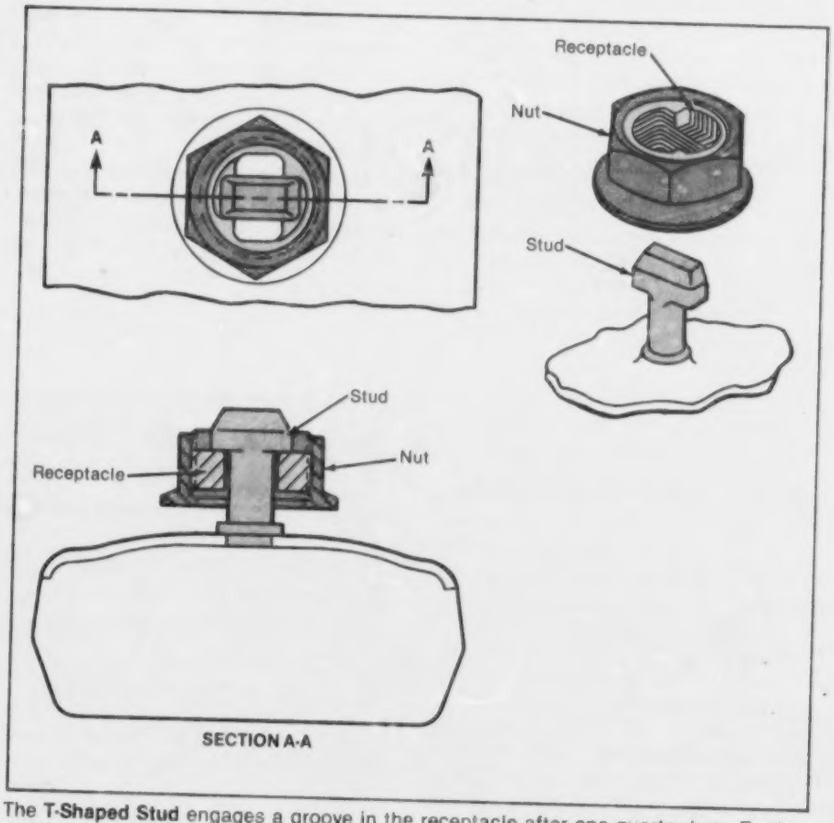
A fastener combines the best features of quarter-turn fasteners and threaded fasteners. Like quarter-turn attaching devices, it can be connected and disconnected quickly. Like threaded devices, it can be adjusted to a desired preload, withstand high loads, and accommodate a wide range of grip lengths.

The fastener consists of two mating parts: a T-shaped stud and a receptacle with an external thread and nut (see figure). The receptacle is placed over the stud and rotated with the nut so that it engages the stud. After one-quarter turn, the nut continues to rotate while the receptacle remains still, so that the nut starts to rotate with respect to the receptacle. With continued rotation, the nut bears against the base of the stud. Finally, the nut is tightened with a torque wrench to the desired prestress.

The reverse procedure removes the fastener. The nut is backed off several turns with a wrench until a lip on the internal thread of the nut engages the bottom of the quarter-turn receptacle: This engagement prevents further rotation of the nut with respect to the receptacle and the receptacle then turns with the nut. An additional quarter-turn disengages the receptacle from the stud.

The fastener was developed for attaching pads to the tracks of tracked vehicles. In this application, it prevents pad separation under tension loads and resists loosening under compression loads. It establishes the required prestress within fairly narrow bounds (± 25 percent) even though the grip length varies widely because of variations in the dimension of the pad plate (a stamping) and the track shoe (a forging). The fastener takes slightly longer to attach than a standard quarter-turn fastener but not as long as a standard threaded fastener.

This work was done by Donald M. Moore of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 34 on the TSP Request Card.*
NPO-16370



The T-Shaped Stud engages a groove in the receptacle after one-quarter turn. Further turning tightens the nut on the receptacle.

Stable Ejection Seat

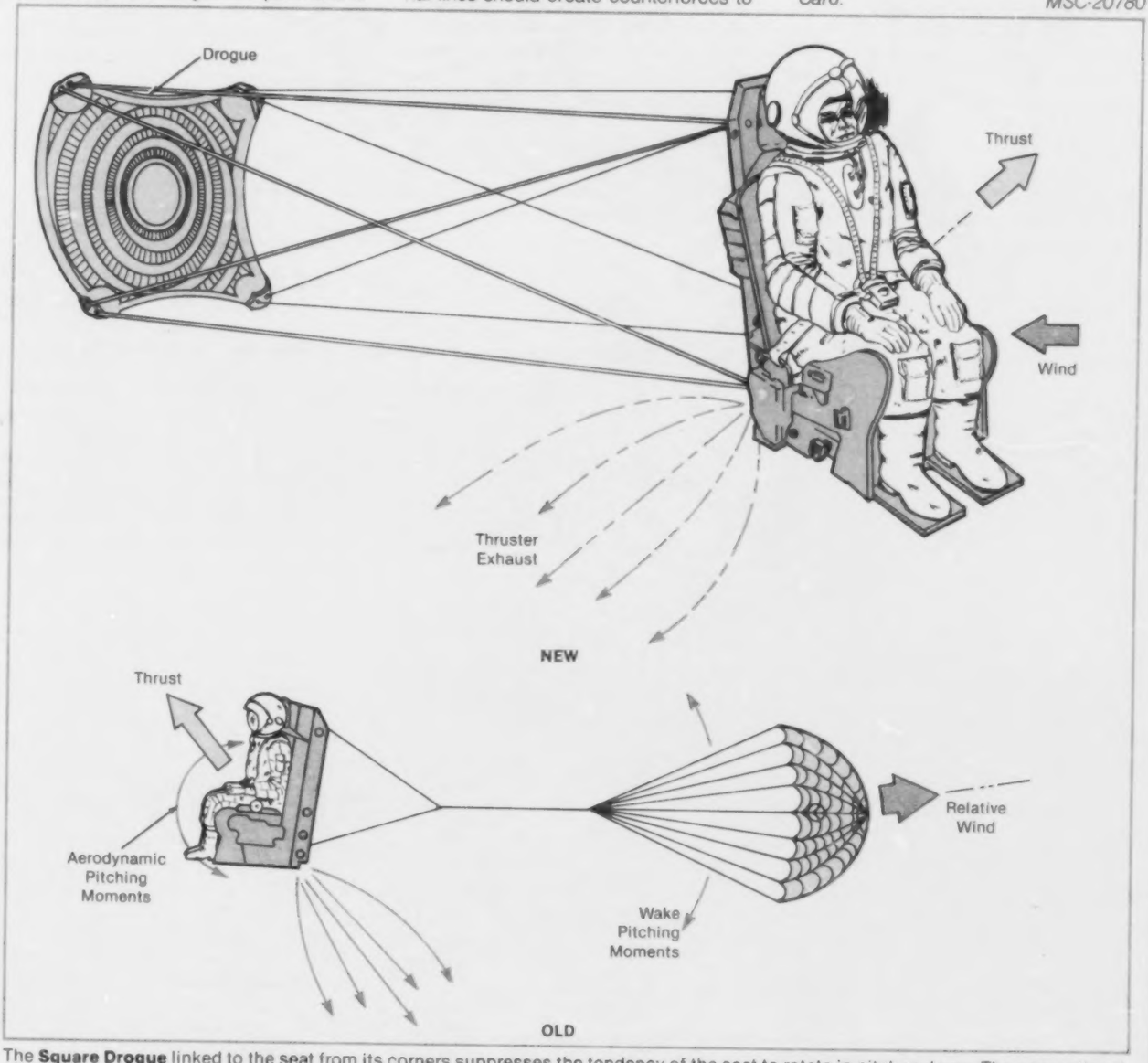
A square drogue with truss-like connections would prevent yaw and pitch of the ejected seat.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed drogue chute for an ejection seat promises to slow down the seat in a more stable fashion than conventional parachutes and thus improve the chances for survival. The new parachute is expected to reduce dynamic forces on the ejected person and extend the maximum possible ejection altitude by 50 percent. It could be used at high or low speeds.

The proposed drogue is square and is attached by a network of lines from its corners to the seat corners (see figure). A conventional ejection parachute, in contrast, is a circular drogue that is attached by a single line to lines extending to the seat corners. The single-point fulcrum attachment can allow pitch and yaw forces to turn the seat and wrap the cable and parachute around the seat. With the new parachute, however, the direct and diagonal lines should create counterforces to the pitch and yaw forces. It should thus allow the seat and its passenger to decelerate and descend stably and safely. With it, gyro stabilization and seat-mounted aerodynamic balancing devices should be unnecessary.

This work was done by Robert S. Hirsch of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 54 on the TSP Request Card.* *MSC-20780*



The **Square Drogue** linked to the seat from its corners suppresses the tendency of the seat to rotate in pitch and yaw. The conventional drogue, however, allows the seat to pivot about the point at which the parachute line is joined to the seat lines.

Finite-Element Fracture Analysis of Pins and Bolts

Stress intensities are calculated in bending and tension.

Marshall Space Flight Center, Alabama

A finite-element stress-analysis method gives stress-intensity estimates for surface flaws on smooth and threaded round bars. Calculations were done for purely tensile and purely bending loads. The results, presented in dimensionless form, will be useful for determining the fatigue lives of bolts and pins.

The first step in the computation is to construct a mathematical model of the part to be analyzed (see Figure 1), using a standard three-dimensional finite element known as quadratic isoparametric. A computer program has been written to take a coarse-element model and refine it in the vicinity of the crack edge. Thus, a sufficient number of elements is provided to characterize the variation of stress intensity along the crack edge.

The mathematical model is considered to be subjected to forces or enforced displacements across the crack edge. Nodal displacements of the elements along the crack are obtained: The forces and displacements are related by a stiffness matrix that has been evaluated for the particular finite-element model by previously developed methods.

The differential displacement at the crack affects the stiffness matrix only through the contributions of the elements adjacent to the crack. The stiffnesses of all other elements of the model remain unchanged. This leads to the observation that the strain-energy release rate due to the crack extension is completely determined by the displacements of only these elements. This rate is calculated from a sum of products of stiffness-matrix elements with displacements. In view of the foregoing observation, only the displacements of the nodes defining the two elements containing the perturbed node (see Figure 2) are required to evaluate this rate.

The stress intensity K_I is calculated from

$$K_I = \left[E \frac{dS}{dA} \left(\frac{1}{1 - \nu^2} + \frac{\nu}{1 + \nu} \frac{\varepsilon_y}{\varepsilon_x + \varepsilon_z} \right) \right]^{1/2}$$

and

$$\frac{dS}{dA} = \frac{dS}{dn} \Big/ \frac{dA}{dn}$$

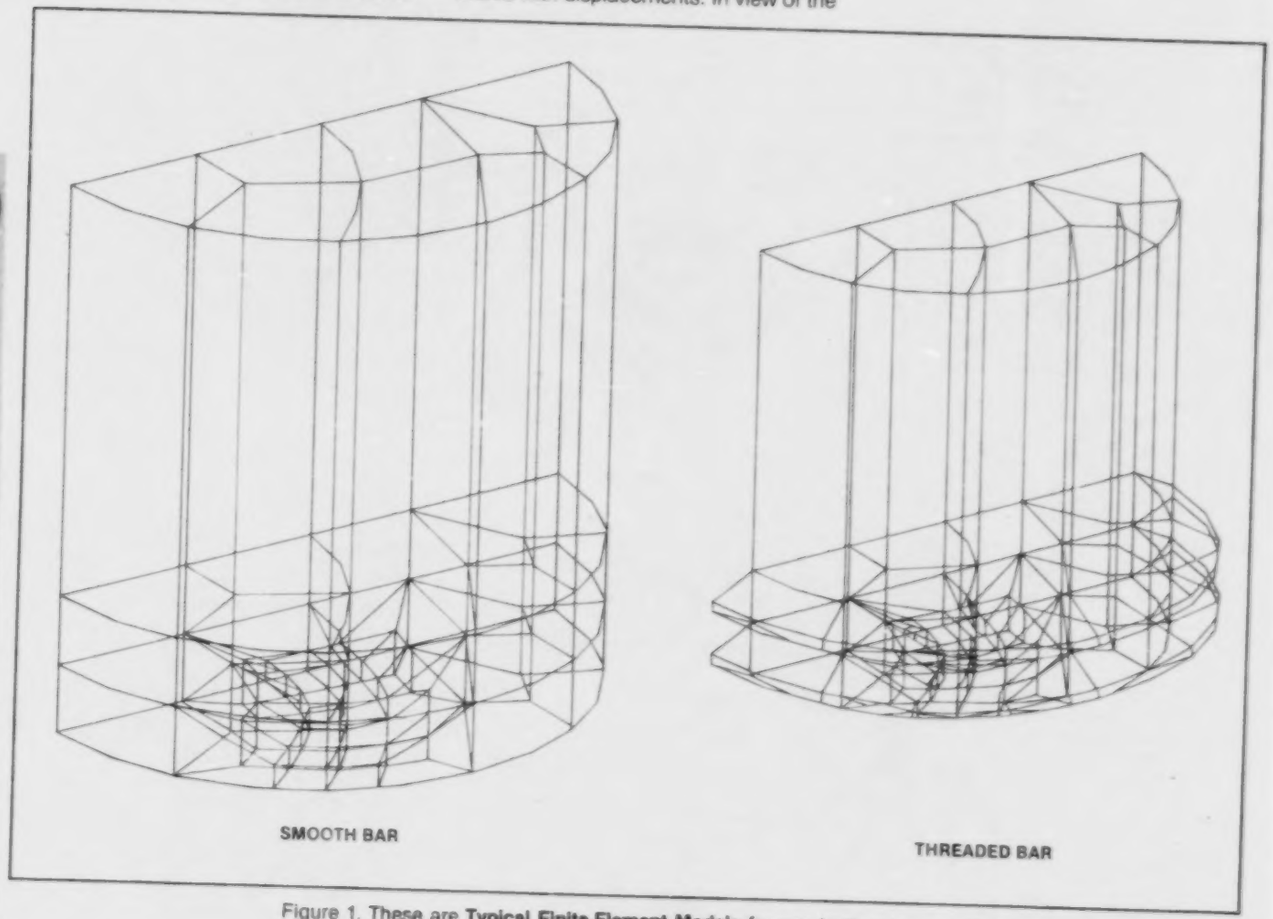


Figure 1. These are **Typical Finite-Element Models** for use in the stress analysis of pins (above) and bolts (below).

where S = strain energy, dn = the element of displacement in the direction of crack growth, A = the surface area of the crack, E = the modulus of elasticity, ν = Poisson's ratio, and ε_x, ε_y, and ε_z represent the strains in the perturbed elements, with ε_y along the crack edge. dA/dn is calculated as a function of the crack size and shape.

The method was verified satisfactorily with a center-cracked strip and an elliptical crack in an infinite medium. The method was then applied to surface flaws on smooth and threaded round bars. For each case, relative stress intensities were calculated and expressed as configuration-related correction factors for a range of crack sizes and aspect ratios. The results of these calculations are comparable to previously published results (where applicable) and are useful in practical problems involving pins and bolts.

This work was done by Kermit J. Nord of Teledyne Brown Engineering Corp. for **Marshall Space Flight Center.** *For further information, Circle 39 on the TSP Request Card.*
MFS-28061

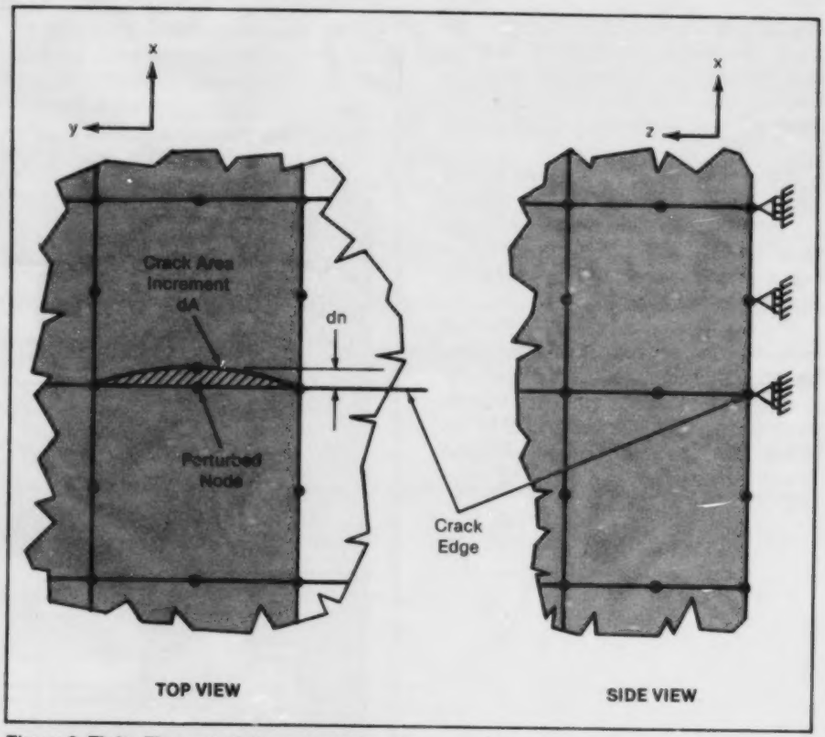


Figure 2. **Finite Elements Adjacent to a Crack** are used to calculate the stress intensity and related quantities involved in crack growth.

Three-Axis Load-Cell Assembly

A force-measuring device is both sensitive and rugged.

Lyndon B. Johnson Space Center, Houston, Texas

A load-cell assembly measures the forces applied to an object along each of three orthogonal axes. It was developed for use with a remote manipulator that bends cryogenic ducts. Usually, the required bending forces are low, but occasionally a substantial force must be applied. The device is therefore designed to be rugged and to function over a wide range, having potential applications in automatic testing equipment, industrial robots, and force-measuring equipment.

Previously, load cells were located in and under the remote manipulator. The repeatability and accuracy of measurement were poor, because the forces sensed by the cells also included those caused by the friction and inertia of the manipulator. The problem became worse when smaller ducts, with smaller deflection forces, were used.

The device is placed between the manipulator and the duct or other object to sense the applied loads directly (see Figure 1). Load cells are mounted on the x, y, and z axes (see Figure 2). Linear ball bushings and an intermediate ring assembly separate the forces acting on the axes. A force in the x

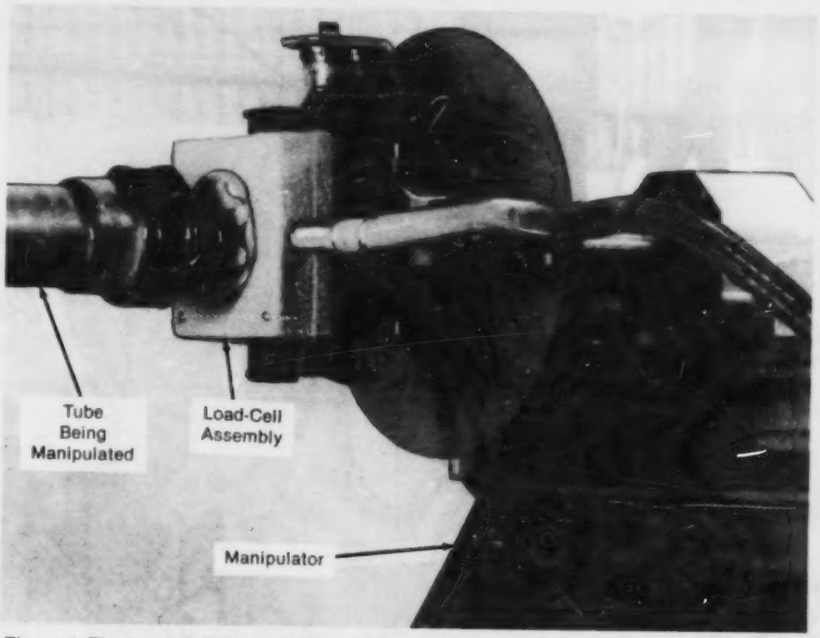


Figure 1. The **Load-Cell Assembly** is placed between a manipulator and the object being manipulated. The load cells thereby measure the forces on the object almost directly, without interference by intervening manipulator forces.

direction, for example, registers only on the x-axis load cell because its bushings, yoke, and intermediate ring assembly allow the cell to accept force only in that direction. Thus, the crosstalk between the three sensors is very low.

Although they are sensitive to low forces, the load cells can withstand much higher forces. Similarly, the ball bushings have low axial friction but can withstand high side loads without being damaged or introducing inaccuracy.

This work was done by Gene R. Rewerts of Ametek, Inc. for **Johnson Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20875.

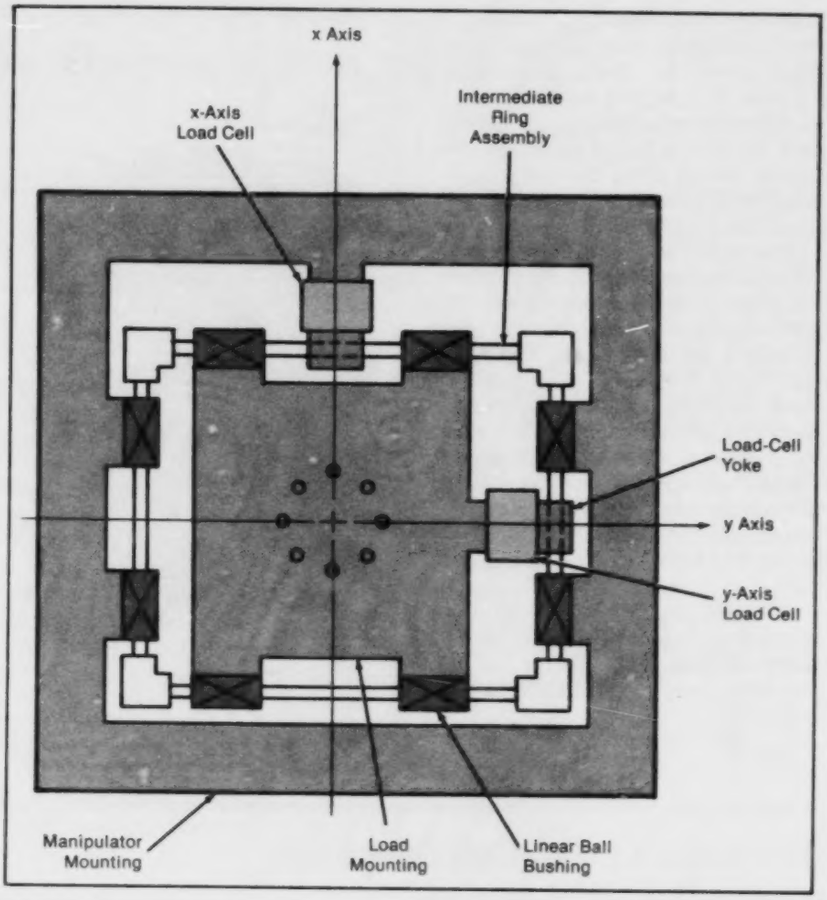


Figure 2. **Load Cells Are Mounted** on three mutually perpendicular axes. The x- and y-axis cells appear in this diagram; the z-axis cell extends out of the page. All cells are similarly equipped with linear ball bushings and intermediate ring assemblies, which isolate the axes from each other.

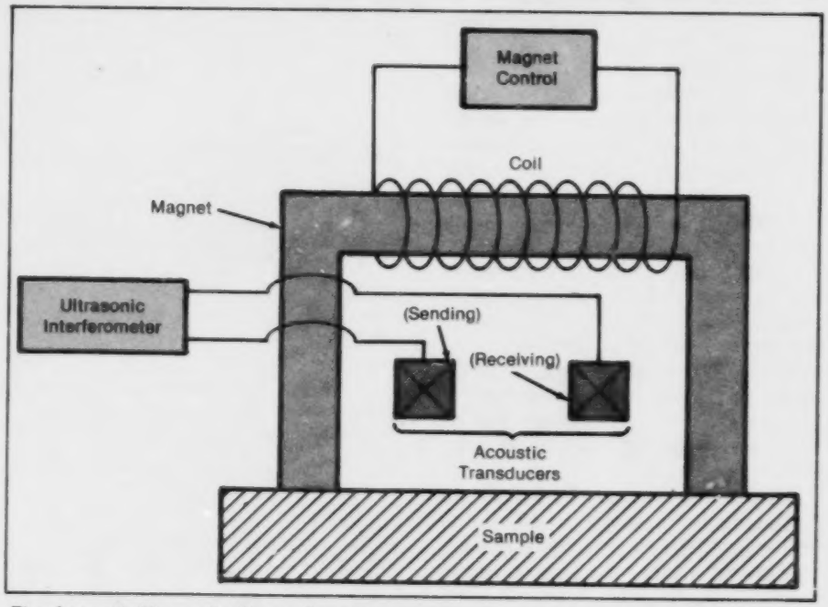
Acoustic/Magnetic Stress Sensor

This high-resolution sensor is fast, portable, and does not require permanent bonding to the structure.

Langley Research Center, Hampton, Virginia

A high-resolution acoustic/magnetic stress sensor measures nondestructively the type (compressive or tensile) and magnitude of stresses and the stress gradients present in a class of materials. The sensor (see figure) includes a precise high-resolution acoustic interferometer, a sending acoustic transducer, a receiving acoustic transducer, an electromagnet coil and core, a power supply, and a magnetic-field-measuring device such as a Hall probe.

The device is portable, fast, nondestructive, and does not require permanent bonding to a structure. The technique requires small magnetic fields and thus fits many applications where magnetization is difficult. Because the sensor functions very well with magnetic steel



The **Acoustic/Magnetic Stress Sensor** measures stress in the sample via the interactions among the magnetic and stress fields and the speed of sound.

solids, it promises to be very useful for alloys.

The sensor uses low magnetic field effects that alter magnetic domains in a way that interrogates local stress fields. The measurement depends on the shift in acoustic velocity that accompanies the change in magnetization. Since stress also changes the magnetic-domain structure, the acoustic measurement senses the presence of stress through the cycling of the magnetic field. Only low magnetic fields can sense the effect on magnetization without compromising effects from the domain-wall rotation that occurs at high fields.

This type of measurement is especially important for construction and applications where steel is widely used. The sensor may be useful especially for the nondestructive evaluation of stress in steel members because of its portability, rapid testing, and nonpermanent installation.

This work was done by Joseph S. Heyman of **Langley Research Center** *and Min Namkung of the College of William and Mary. For further information, Circle 96 on the TSP Request Card.*
Card. LAR-13320

Matching Vibration Testing to "Real-World" Conditions

Vibration spectrum of test machine is adjusted to that observed in operation.

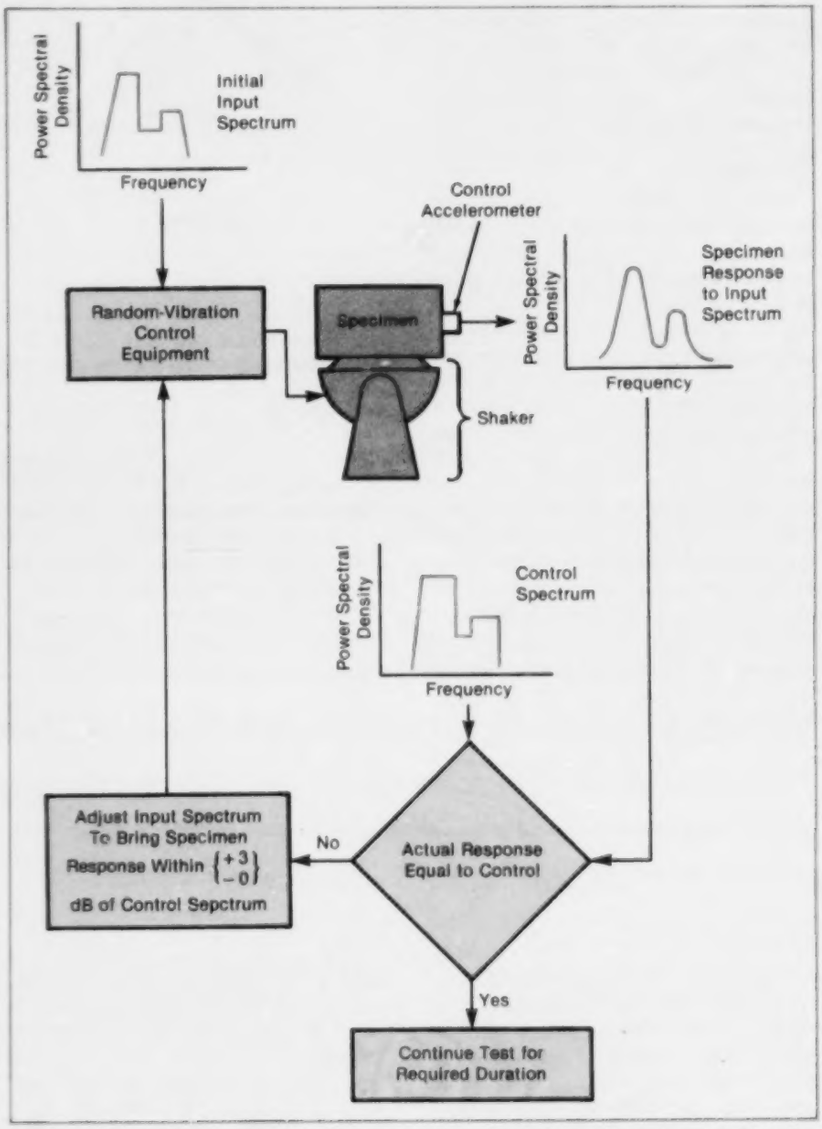
Lyndon B. Johnson Space Center, Houston, Texas

A method for vibration testing uses feedback to ensure that a test specimen is exposed to the same vibration spectrum that it would experience in service. In a conventional vibration test, the specimen and its mounting fixture are subjected to a preset excitation spectrum. This spectrum may not cause the correct vibrational response of the specimen because the support fixture may amplify, attenuate, or otherwise alter the vibrational response.

First, the vibrational response of the specimen to random excitation is measured in service. From the in-service spectral response, an arbitrary worst-case spectral response (maximum amplitude as a function of frequency) is constructed from these measurements and is called the "control" spectrum. An estimate is also made of the input spectral setting that ought to cause the shaker table to produce a specimen spectral response like that of the in-service tests.

A test specimen is placed in a test fixture and attached to a shaker (see figure). The shaker is initially operated at one-quarter the full level of the input spectrum to prevent overloading. A short vibration test is run, and the specimen response is compared to the control spectrum. The input spectrum is then adjusted until the response resembles the control spectrum.

This work was done by Albert D. Olsen, Jr., of Beech Aircraft Corp. and Albert V. Keblaitis of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 58 on the TSP Request Card.*
MSC-20665



In an Iterative Procedure, the vibrational response of a test specimen is matched to the previously-determined worst-case in-service response. An accelerometer on the test specimen provides feedback.

Stress Measurement by Geometrical Optics

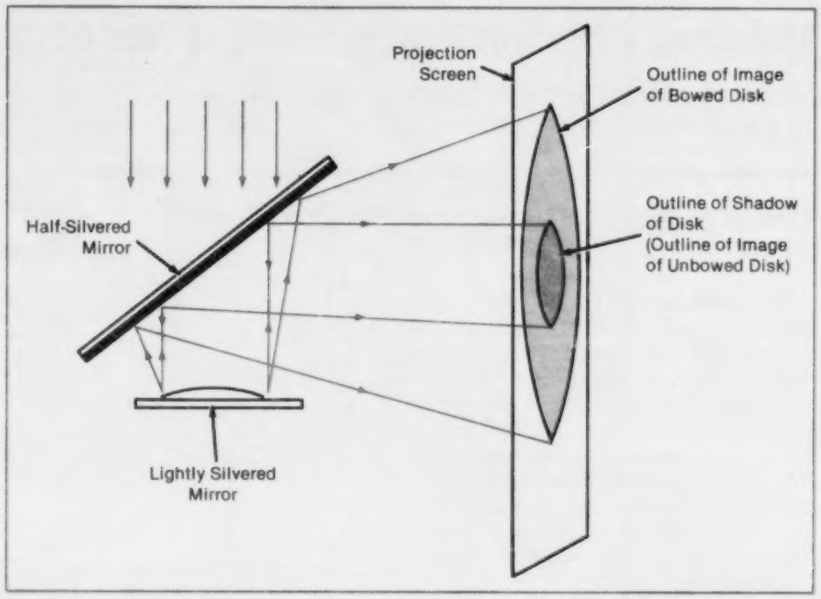
A fast, simple technique measures stresses in thin films.

Lewis Research Center, Cleveland, Ohio

A new, quick, and accurate method employing geometrical optics has been developed to measure stress in thin films. The stress in a thin film on a bulk substrate is an important factor relating to the film's adhesion and behavior under temperature variation. If the stress in the film becomes large enough, it will exceed the adhesion of the film/substrate interface, and the film will fail.

Present stress-measuring techniques, such as Newton rings, surface analyzers, and others, are rather complicated and time consuming, requiring up to 30 to 40 minutes for a typical measurement. The new method applying geometrical optics reduces it to a minute or less without sacrificing accuracy.

When a thin film is deposited on a very thin substrate, such as a common microscope cover slide, it will deform the substrate because of the stress buildup in the film. From the radius of the curvature of the film, the stress can be determined. Geometrical optics are applied to project the image of the stressed film by a laser light beam onto a screen (see figure). The measurement of the focal length of the "spherical mirror" closely approximates the radius of curvature of the thin film. Any magnification or contraction of the image of the film is indicative of the distortion of the substrate due to the film stress. Such magnification, whether greater or less than one, immediately determines the sign of stress.


Projection Screen
Outline of Image of Bowed Disk
Outline of Shadow of Disk (Outline of Image of Unbowed Disk)
Half-Silvered Mirror
Lightly Silvered Mirror

The **Sample Disk Is Bowed** by stress into an approximately spherical shape. The reflected image of the disk is magnified by an amount related to the curvature and, therefore, to the stress.

The geometrical optics method for measuring stress in thin films is simple, quick, and accurate. The method requires a sample substrate, such as a cheap microscope cover slide, two mirrors, a laser light beam, and a screen.

This work was done by Raymond S. Robinson and Stephen M. Rossnagel of Colorado State University for **Lewis Research Center.** *Further information may be found in NASA CR-168172 [N84-18322/NSP], "Sputtering Phenomena in Ion Thrusters" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. LEW-14169*

Variable Control Port for Fluidic Control Device

The volume and velocity of the control flow can be independently adjustable.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed throttling mechanism can adjust the size of the control port of a fluidic vortex flow-control device. This would allow independent adjustment of the volume and the velocity of the control flow — to match a wider range of supply and output requirements.

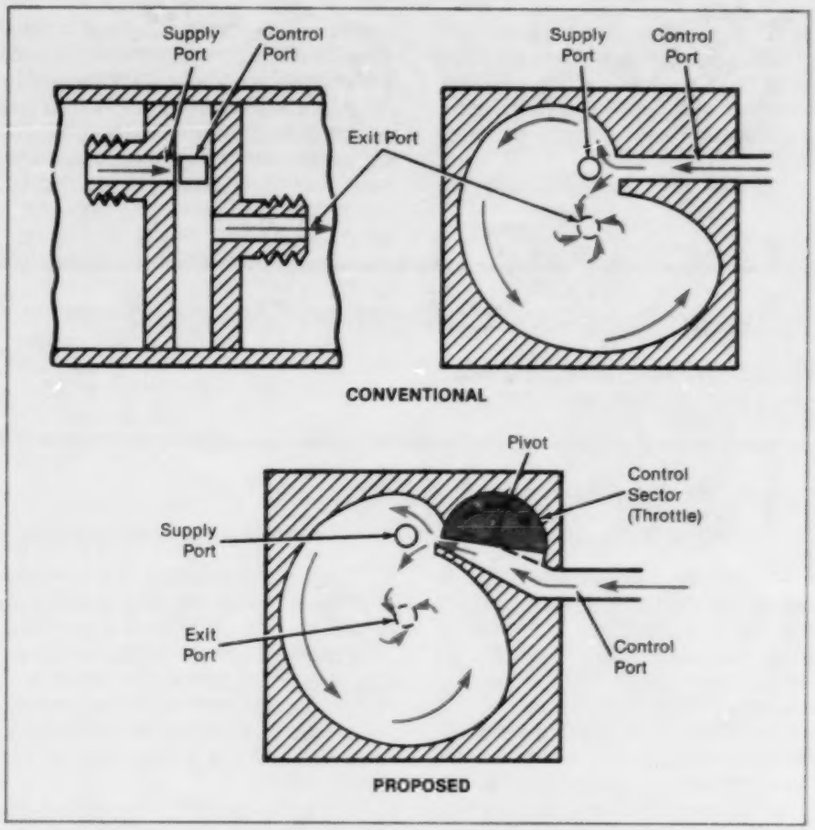
In a conventional fluidic vortex flow-control device (see top of figure), the control fluid strikes the supply fluid (the fluid to be controlled) at a right angle. The supply fluid enters the vortex chamber through the supply port. The control-fluid motion pushes the supply fluid into a vortex that circulates along the walls of the chamber. As the control flow is increased, the vortex is accelerated, delaying the exit of the combined fluids through the centrally-located exit port.

The volume and pressure of the control fluid entering the chamber are determined by the pumping pressure exerted against the control fluid and the hydraulic head losses of the control-flow tubing and the control port; the higher the control-fluid pressure, the greater the volume and velocity of the control-fluid jet striking

the supply-fluid stream. For a given control-fluid pressure, the head loss, and hence the control flow, depends on the cross-sectional area of the control port. In any one device, this area is fixed; if it does not fit a desired set of supply/output control conditions, the device must be replaced by another having a different ratio of supply- and control-port geometries. While in the laboratory, this device allows the output-flow rate to vary by up to a factor of 5; under field conditions, it is more common for this rate to vary by as little as a factor of 2.

In the proposed device (see bottom of figure), a rotatable D-shaped control sector could throttle down the control port or open it completely and could be set to any intermediate control-port cross-sectional area. Although this adjustment would affect the volume and control-port head loss, the volume and velocity could be controlled independently by also adjusting the fluid-supply pressure. This would allow adjustment to a wider range of control conditions and the ability to maximize control efficiency. Fluidic control theory suggests the possibility of improvement in the control ratio of at least 2:1 over conventional devices.

This work was done by Earl R. Collins, Jr., of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 32 on the TSP Request Card.*
NPO-16603



A Fluidic Vortex Flow-Control Device of the conventional type (above) has a control port of fixed cross section. In the proposed device (below), the control port is equipped with a throttle to enable the independent adjustment of control-flow volume and velocity.

Measuring Water-Layer Thickness

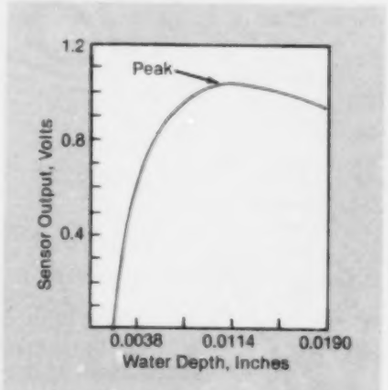
The technique uses an optical proximity detector.

Langley Research Center, Hampton, Virginia

The feasibility of determining the thickness of a water layer above a surface has been investigated by use of a commercially-available optical proximity detector. The detector is a noncontacting instrument, and it measures linear distance, displacement, or motion by means of light rays.

The detector consists of a sensing probe, a cartridge containing a photocell and light source, and an electronics package, housed in a metal carrying case. Light transmitted from the fiber-optic probe is reflected by the observed surface and transmitted back through the probe to a photoreceiver, the output of which is indicated on a digital voltmeter or other suitable instrument.

The sensor is specified to have high sensitivity [permitting measurements in millionths of an inch (several one-hundredths of a micrometer)], to have linear output with distance over a significant operating range, and to possess a significant frequency response. As the distance between the probe and the surface increases, there is a rapid increase in signal level until it reaches a peak. Beyond the peak, the output sensitivity changes sign, and the detector becomes less sensitive to changes in distance.



The **Water-Depth Measurement** is limited to about 0.011 in. (0.28 mm), the region to the left of the peak, because of the equipment design.

A test was performed to determine whether this sensor could be used in determining water-layer thickness. A 0.032-in. (0.81-mm) fiber-optic probe with random fiber configuration was sealed through the bottom of a plastic container. Water was added, and the output voltage versus water depth above the probe was plotted. It was found that reflection does occur, and the output voltage increases with the water level, reaches a peak, then begins to decrease.

Several problems arose. Zero water depth over the sensor was uncertain because of meniscus effects. It was also

found that output voltages increased with increasing light levels and with the presence of bubbles above the probe. Furthermore, the water-depth range (see figure) of about 0.011 in. (0.28 mm) was very limited.

Despite these shortcomings as an accurate water-depth-measuring instrument, the sensor could possibly be used to detect the presence of bubbles or particles in a water stream or to trigger an alarm when condensing water becomes present in the bottom of a supposedly dry tank. Fiber-optic probes of sizes up to 0.285 in. (7.24 mm) with varying sensitivities and configurations are available for use with this system.

This work was done by Nettie Faulcon of **Langley Research Center.** *For further information, Circle 99 on the TSP Request Card. LAR-13347*

Dynamic Pressure Calibration Standard

Vibrating columns of fluid are used to calibrate transducers.

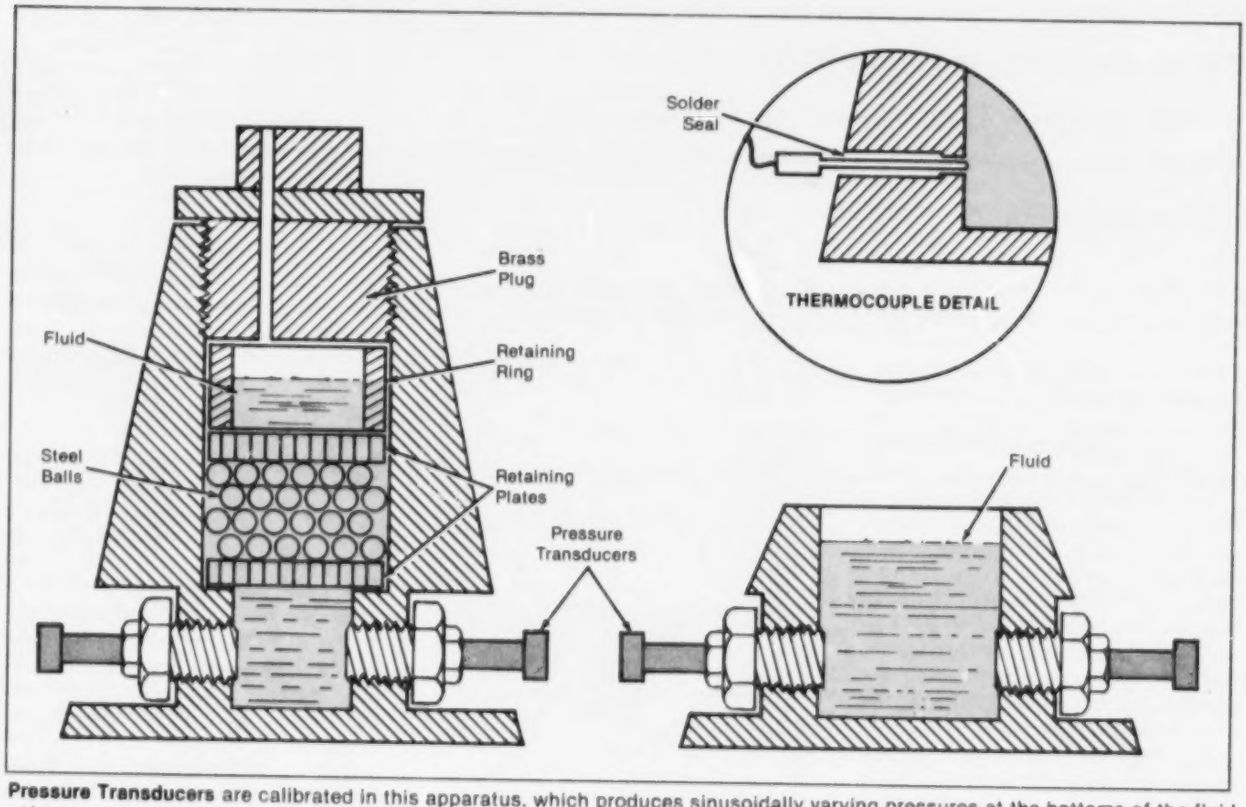
Langley Research Center, Hampton, Virginia

Advancements in wind-tunnel testing capabilities and needs for increased aircraft performance have given rise to greater accuracy requirements for the measurement of dynamic pressures. However, a recognized national standard for dynamically calibrating pressure transducers does not exist. In a step toward meeting this need, a dynamic pressure calibration standard has been developed for calibrating flush diaphragm-mounted pressure transducers. Pressures up to 20 kPa (3 psi) have been accurately generated over a frequency range of 50 to 1,800 Hz.

The system includes two conically shaped aluminum columns (see figure), one 5 cm (2 in.) high for low pressures and another 11 cm (4.3 in.) high for higher pressures, each filled with a viscous fluid. Each column is mounted on the armature of a vibration exciter, which imparts a sinusoidally varying acceleration to the fluid column.

Pressure transducers mounted at the bases of the columns sense the sinusoidally varying pressures. These pressures are determined from measurements of the density of the fluid, the height of the fluid, and the accelerations of the columns. A section of the taller column is filled with steel balls to control the damping of the fluid to extend its useful frequency range. The short column has a sufficiently-high natural frequency so that no damping is required. The vibration armature and the standard are enclosed in a chamber that is thermally and acoustically insulated. The chamber is equipped with an air-conditioning unit for thermal control.

The data are recorded using two digital multimeters, a frequency counter, and a



Pressure Transducers are calibrated in this apparatus, which produces sinusoidally varying pressures at the bottoms of the fluid columns. Accurate calibrations are obtained up to 20 kPa.

desk-top computer. The computer records the data from the multimeters, displays the data in both graphic and tabular forms, and stores them on a disk. A bell-jar evacuation system is used to evacuate the fluid to remove entrapped gases, which cause cavitation and degradation in the viscosity and density of the fluid. Quartz piezoelectric pressure transducers are used because of their minimal diaphragm deflection due to pressure, their high natural frequency, and compatibility with the calibration fluid.

This standard has a total measurement uncertainty of ±5.95 percent and an average repeatability of ±2.5 percent for pressures up to 5 kPa (0.75 psi) using the shorter column. From 5 kPa to 20 kPa (3 psi), the measurement error of the taller column increases to ±10 percent and an average repeatability of ±3.2 percent due to mechanical resonances and acceleration gradients within the column. The signal noise is low, and the waveform is highly dependent on the quality of the drive signal in the vibration exciter.

This work was done by Paul C. Schutte and Kenneth H. Cate of **Langley Research Center** *and Steven D. Young of the West Virginia Institute of Technology. For further information, Circle 13 on the TSP Request Card.*
LAR-13443

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Mixer Analysis of Nacelle/Nozzle Flow

Flow over an idealized nozzle is computed.

The calculation of the flow field around an actual mixer nozzle is a formidable task. It is generally worthwhile to first consider an idealized version of such a problem before undertaking a calculation of the general case. A NASA/Contractor report describes an idealized analysis and computer program made for the mixer problem.

The analysis and computer program calculate the flow over an idealized mixer nozzle. The nozzle is idealized by unwrapping it so that the planform lies in the $z = 0$ plane. Linearized compressible flow is used to calculate the flow and the mixer shape given the loading on the mixer.

The loading is chosen to satisfy the Kutta condition at the mixer trailing edge, and the loading in the vicinity of the trailing edge has a square-root-of-x behavior to give a smooth flow in this region.

A set of computer programs and sub-routines is given for calculating the flow field. The overall program is given the name PLANMIX, and sample calculations of the individual programs are given.

Work now remains on the interpretation of the results of the computer program. The end goal is to achieve the maximum amount of mixing downstream of the mixer while retaining a reasonable shape for the mixer. Because the analysis assumes linearized flow, calculation of the effects of deep lobe penetration cannot be made using this program.

This program was written by T.J. Barber and R. Amiet of United Technologies Corp. for **Lewis Research Center.** *For further information, Circle 95 on the TSP Request Card.*
LEW-14073

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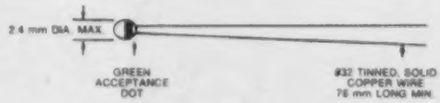

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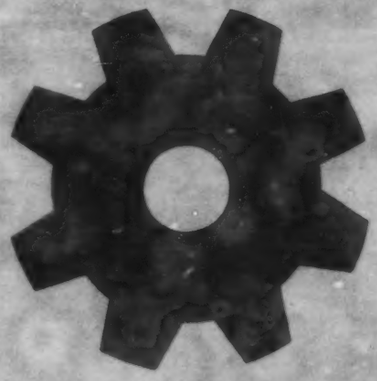

Hardware, Techniques, and Processes

118 Device for Extracting Flavors and Fragrances
119 Multipurpose Scribing and Drawing Tool
120 Variable-Force Eddy-Current Damper
127 Improved Seal for NTF Fan Shaft
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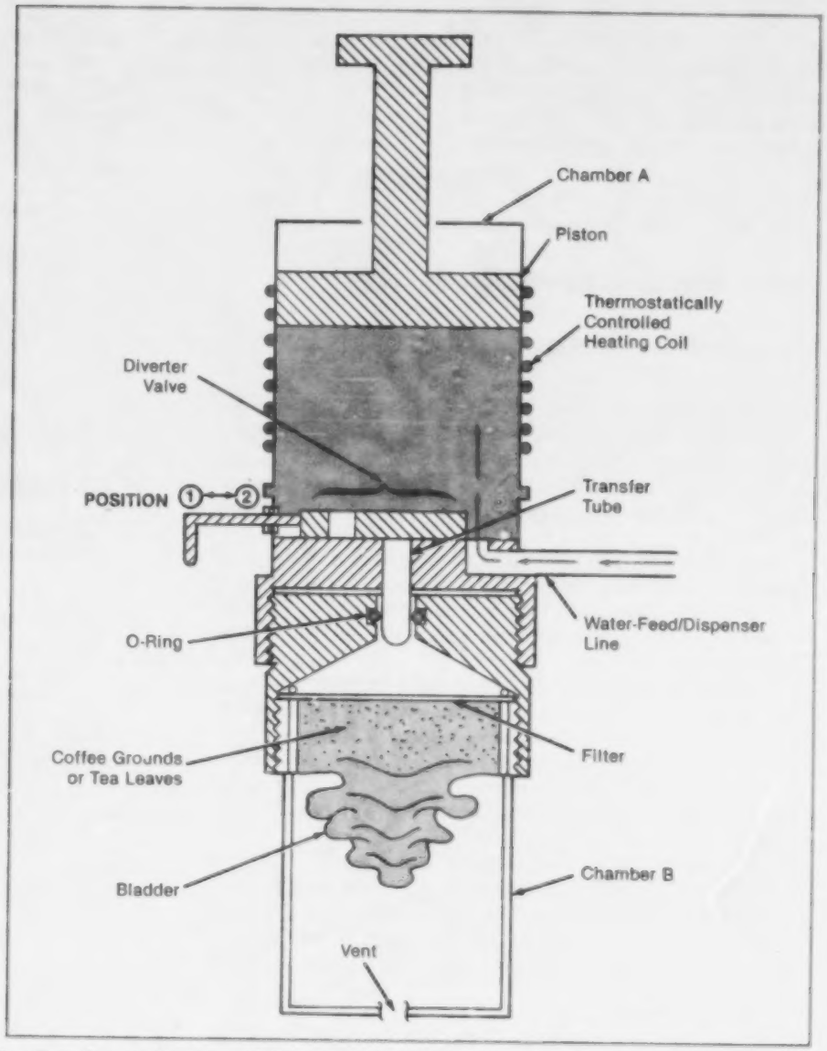
Device for Extracting Flavors and Fragrances

Pressurized extraction apparatus may have industrial uses.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed machine for making coffee and tea in a weightless environment may prove even more valuable on Earth as a general extraction apparatus. The machine functions like a conventional coffeemaker during part of its operating cycle and includes additional features that enable operation not only in zero gravity but also extraction under pressure in the presence or absence of gravity.

Coffee- and teamaking is similar to other processes for extracting flavors and fragrances from plants by means of cold or hot water, alcohol, or other solvents. Because the proposed system is enclosed, volatiles are contained: It is important to prevent the loss of volatile constituents since they are often important parts of flavors and fragrances. Also, because the system is enclosed, it can be pressurized for such processes as supercritical solvent extraction or pressurized fermentation. A bench-scale general pressurized-extraction apparatus would be useful in research and



The **Zero-Gravity Beverage Maker** uses a piston instead of gravity to move the hot water and beverage from one chamber to the other and to dispense the beverage.

development.

The figure shows the machine during the first part of the beverage-making cycle. The stages of the cycle are as follows:

1. With the diverter valve in position 1, water is fed into chamber A, forcing the piston up until it reaches the limit of its travel or until the desired amount of water has been fed in.
2. The thermostatically controlled heater is turned on, raising the temperature of the water to about 100° C.
3. The diverter valve is moved to position 2. The piston is pushed down, forcing the water through the transfer tube and the filter into the coffee grounds or tea leaves. The liquid/solid mixture is contained in a bladder in chamber B.
4. The piston is pulled up to suck the coffee or tea liquid into chamber A. The filter retains the grounds or leaves in chamber B.
5. Once the coffee or tea liquid is in chamber A, the diverter valve is returned to position 1. The water-feed/dispenser line is disconnected from the water supply and connected to a cup or other beverage container. The beverage is dispensed by pushing on the piston.
6. The beverage is kept warm in chamber A by the thermostatic heater.

This work was done by Franklin R. Chang of **Johnson Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20761.

Multipurpose Scribing and Drawing Tool

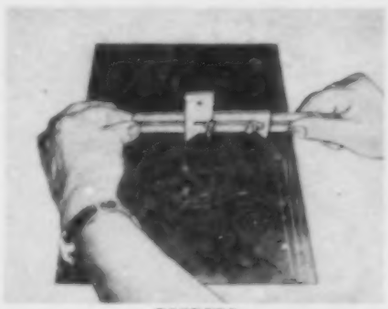
A two-part tool can be reconfigured for a variety of jobs.

Lyndon B. Johnson Space Center, Houston, Texas

A multipurpose tool speeds up the laying out of patterns on sheet metal, wood, plastic, or paper. The tool can be carried in a pocket, then quickly assembled for service as a height gauge, pair of dividers, protractor, surface gauge, or square (see figure). For example, the tool can be used to scribe several parallel lines for rivet holes on a long sheet of metal, then reassembled as a pair of dividers to mark the other axes of the rivet holes. The tool can be used as a scribe or with a pencil, depending on the material to be marked.

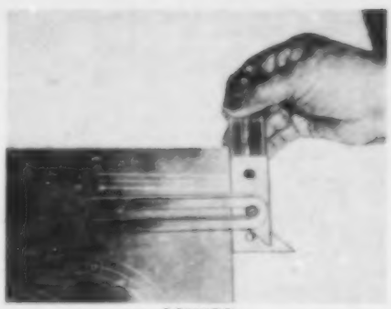
The tool consists of two elongated, flat, slotted parts with winglike protuberances that serve as cutters, pencil holders, and supports. The parts are held together by a pair of screws and wingnuts in various configurations, depending on the function required of the tool. The user can thus easily and quickly change the configuration.

This work was done by James M. Ellis of **Johnson Space Center.** *For further information, Circle 65 on the TSP Request Card. MSC-20913*



DIVIDERS

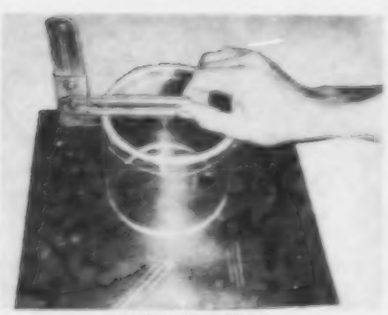
HEIGHT GAUGE



SQUARE

PROTRACTOR

WITH PENCIL



SURFACE GAUGE

This **Tool Performs Several Functions** useful in layout. Lines, curves, and angles are made visible as either bright scribe marks or as dark pencil (or ink) marks.

Variable-Force Eddy-Current Damper

Variable damping is achieved without the problems of containing viscous fluids.

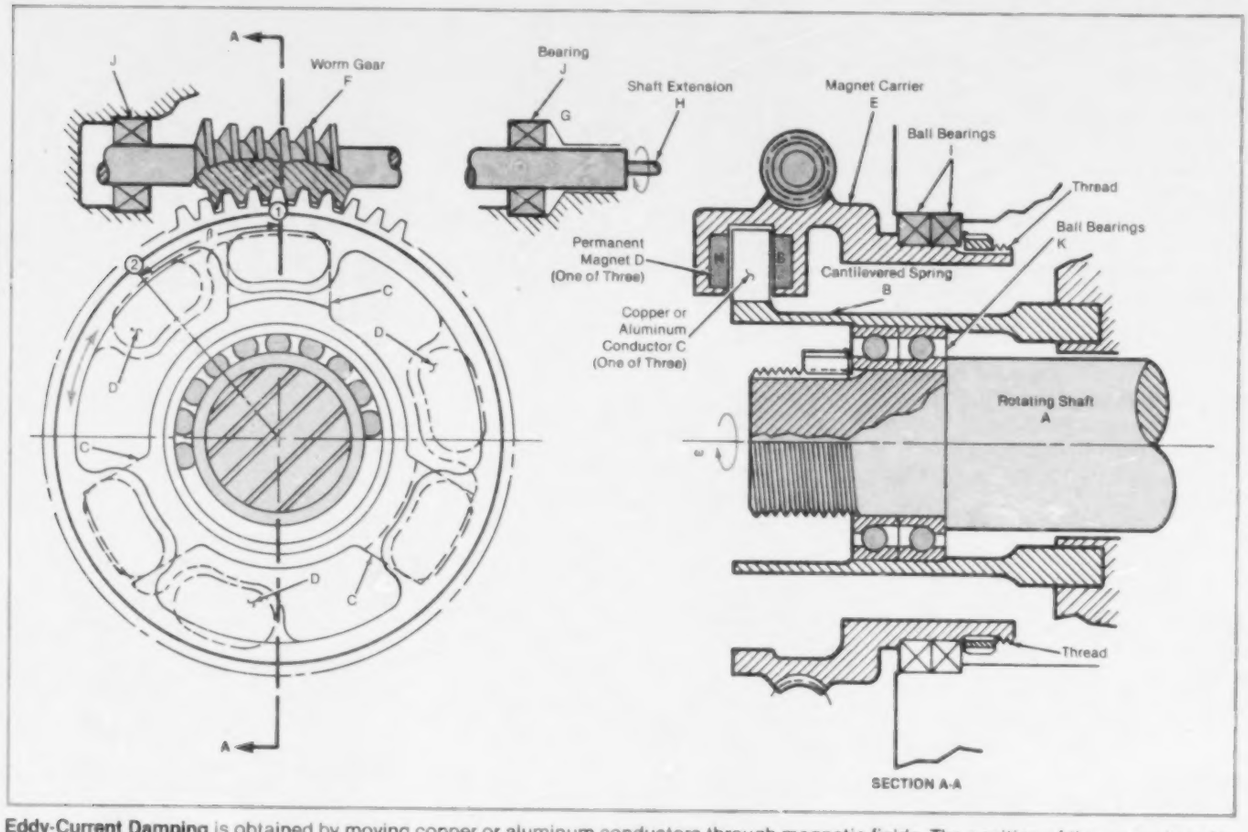
Lewis Research Center, Cleveland, Ohio

An eddy-current damper has been conceived and tested that provides the capability of varying, either manually or automatically, the stiffness and damping characteristics of a rotor or shaft-support system without having to bring the rotor to rest. This variable damping force and stiffness can also be provided without the need for viscous fluids. Fluid-film dampers, which employ a viscous fluid film between relatively moving parts, are used in a number of contemporary turbomachines. Examples would be turbojet aircraft engines, radial and axial compressors, and oxygen expanders (high-speed gas liquefiers), to name just a few. Vibrational energy induced in the rotor and transmitted to the bearing supports is dissipated as heat in shearing the viscous fluid.

The so-called "squeeze-film" damper dissipates the energy by pumping a viscous fluid in and out of a narrow annulus. In these types of dampers, the amount of damping and stiffness is determined by the original design and calculated amplitudes of vibration that are expected to be encountered. Should actual operating conditions differ from those anticipated, there is normally no method provided for altering the damper characteristics, once the damper has been installed. Also, for this damper to be effective, it must be supplied with relatively large quantities of a viscous fluid. This means, in most cases, that these dampers are required to be located very close to a bearing where lubricating oils are available in large quantities.

An eddy-current damper, not requiring lubricating oils, is free to be positioned at other locations in the machine. In fluid viscous-shear dampers, the magnitudes of damping and stiffness are functions of fluid viscosity, clearances between relatively moving surfaces, and temperature. Without a means of external adjustments or control, too much stiffness and damping for any given set of vibrational frequency and amplitude can result.

The variable-force eddy-current damper operates as depicted in the figure. One end of a rotating shaft, A, turns in ball bearings K. The outer races of the ball bearings are fixed from rotating in a cantilevered type of spring, B, which is fixed in the machine frame. When shaft A is caused to vibrate with a measurable amplitude, as is produced by rotating unbalance forces, it causes the cantilever spring mount to precess in an orbital motion, and predominantly in a plane perpendicular to the rotor axis. An electrically



Eddy-Current Damping is obtained by moving copper or aluminum conductors through magnetic fields. The position of the magnet carrier determines the amount of field engagement and, therefore, the amount of damping.

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34☐ Telecommunications Engineer
35☐ Applications Engineer
36☐ Systems Engineer
39☐ Engineer—Other (specify)
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46☐ Medical Doctor
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48☐ Systems Analyst
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M☐ Machinery
S☐ Industrial Controls/Systems
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64 ☐ Product Planning Dir/Manager
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14 ☐ Section Head
19 ☐ Group Leader
65 ☐ Manager Information Science
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68 ☐ Quality Assurance Dir/Mgr
69 ☐ Project Leader
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23 ☐ Mechanical Engineer
24 ☐ Chemical Engineer
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27 ☐ Environmental Engineer

28 ☐ Ocean/Naval Engineer
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This work was done by Robert E. Cunningham of **Lewis Research Center.** *Further information may be found in "Preliminary Results on Passive Eddy Current Damper Technology for SSME Turbomachinery." To obtain a copy, Circle 82 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Council, Lewis Research Center [see page 29]. Refer to LEW-13717.

Improved Seal for NTF Fan Shaft

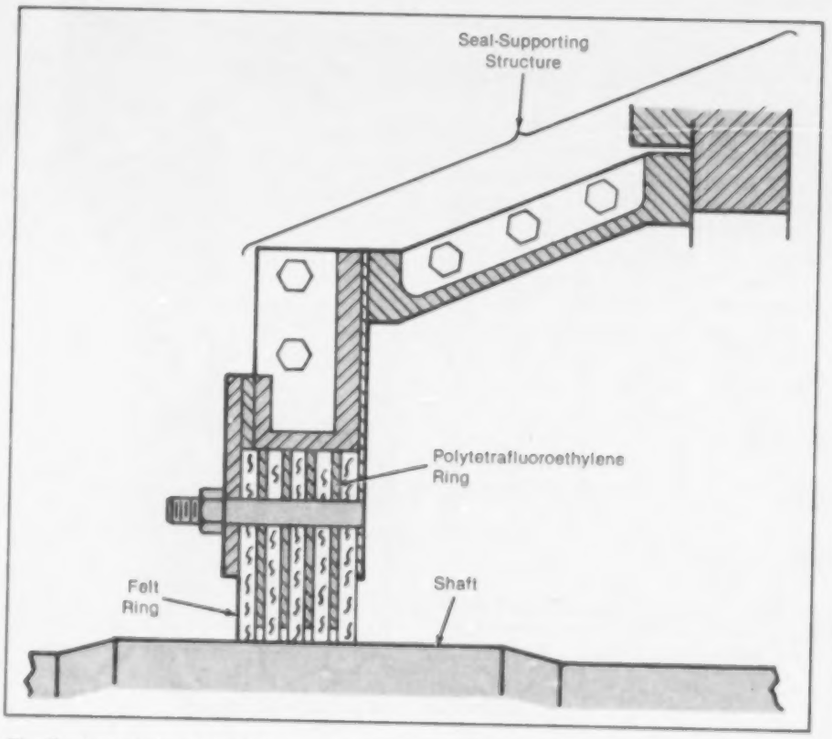
The new seal is more effective and lasts longer.

Langley Research Center, Hampton, Virginia

The National Transonic Facility (NTF) main-drive fan hub and part of the drive shaft are housed in the upstream nacelle, which provides both structural support and an aerodynamic fairing for the assembly. Inside the nacelle, nitrogen-gas flow is restricted by a seal around the fan shaft at the upstream nacelle bulkhead. Operational temperatures from +150° to −320° F (+66° to −196° C), absolute pressures from 8 psi to 130 psi (55 kN/m^2 to 900 kN/m^2), and a pressure differential of 2 psi (14 kN/m^2) combined with severe bulkhead thermal distortions result in a very serious design problem. The problem is compounded by the 600-r/min shaft speed. A conventionally designed seal using glass fibers and polytetrafluoroethylene proved to have an operating life of only a few hours.

An analysis of the seal failure revealed two causes. The first, bulkhead thermal distortion, was alleviated by relocating the seal to another part of the shaft. The second cause was shaft surface speed; the 48.5-in. (123.2-cm)-diameter shaft turning at 600 r/min has a surface speed of 7,600 ft/min (38.7 m/s), which is much too high for most materials.

To improve the seal efficiency, a high-density wool felt treated with a fire retardant was incorporated into the final design.



The **Seal** consists of five felt rings interspersed with four polytetrafluoroethylene rings having an inner diameter slightly larger than that of the shaft. The spaces between the polytetrafluoroethylene rings and the shaft produce a labyrinth effect, which increases the degree of sealing.

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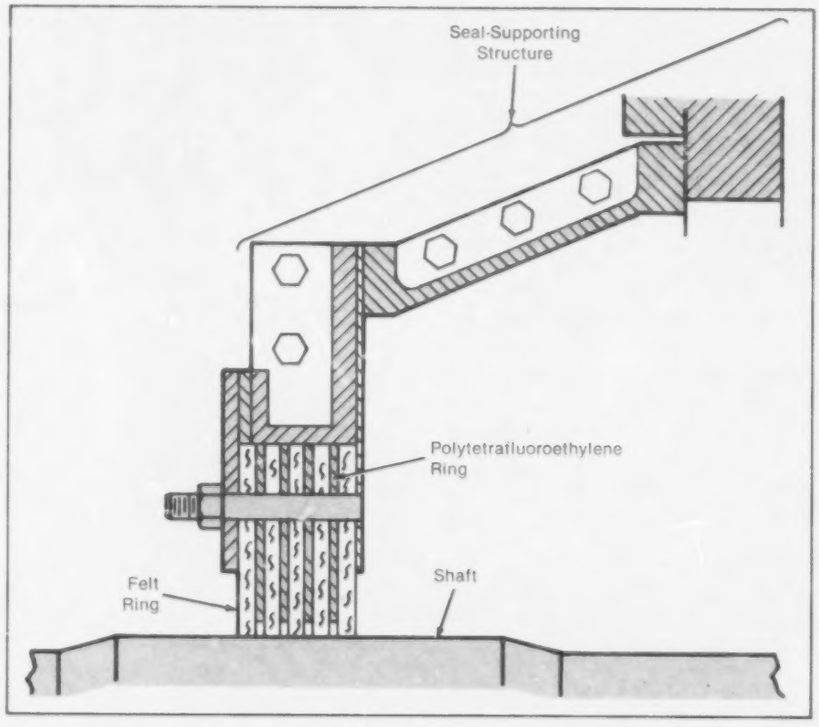


The Seal consists of five felt rings interspersed with four polytetrafluoroethylene rings having an inner diameter slightly larger than that of the shaft. The spaces between the polytetrafluoroethylene rings and the shaft produce a labyrinth effect, which increases the degree of sealing.

The commercially purchased felt sheets 1/4 in. (6 mm) thick were cut into 90° segments, four segments to a ring. Polytetrafluroethylene spacers were cut in a similar manner from sheets 1/8 in. (3 mm) thick. The seal (see figure) is made up of five felt rings, separated by four polytetrafluoroethylene rings held in place by an aluminum structure. The seal runs on a 9-percent-Ni steel shaft treated with a MoS_2 surface-bonded lubricant. Since the polytetrafluoroethylene rings are slightly larger than the shaft, a small cavity is formed on either side of the felt rings, providing the labyrinth effect, which improves the seal efficiency.

This work was done by E. A. Crossley, Jr., Jeffrey A. Jones, Roger Messier, and G. Warren Johnson of **Langley Research Center** *and Keith Felton of North Carolina State University. To obtain a set of nine construction drawings, Circle 97 on the TSP Request Card.*
LAR-13218

Gentle End Effector for Robots

A gripper handles electronic components without damaging them.

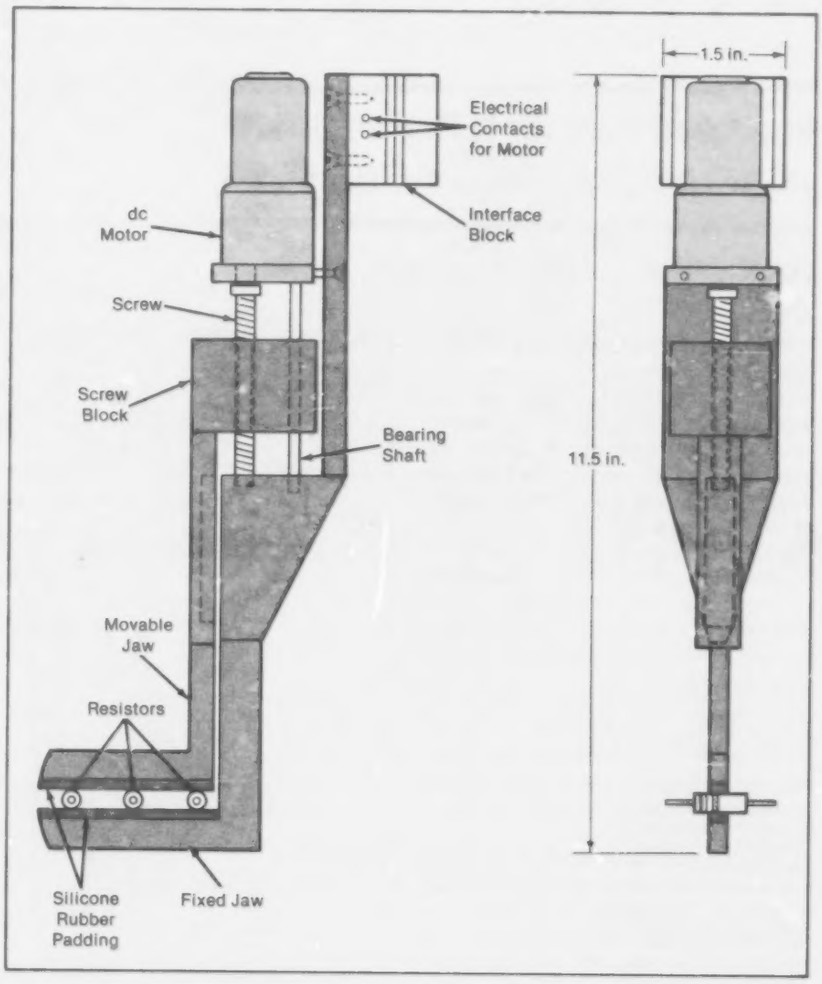
Marshall Space Flight Center, Alabama

An end effector for a robot handles delicate small parts firmly but gently. It grips such electronic components as resistors, capacitors, and transistors without damaging them and holds them during soldering or other processing.

Designed for use with a Puma (or equivalent) robot arm, the end effector is driven by a dc motor instead of the usual pneumatic drive. The motor is mounted on the fixed jaw of the effector and drives the movable jaw through a screw block (see figure).

The end effector grips components between the fixed and movable jaws. The jaws are made of steel, and their gripping surfaces are lined with silicone rubber to cushion and therefore further reduce the chance of damaging the components. The jaws withstand soldering temperatures in excess of 500°F (260°C).

This work was done by Winston S. Webb of Honeywell Inc., for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-28119

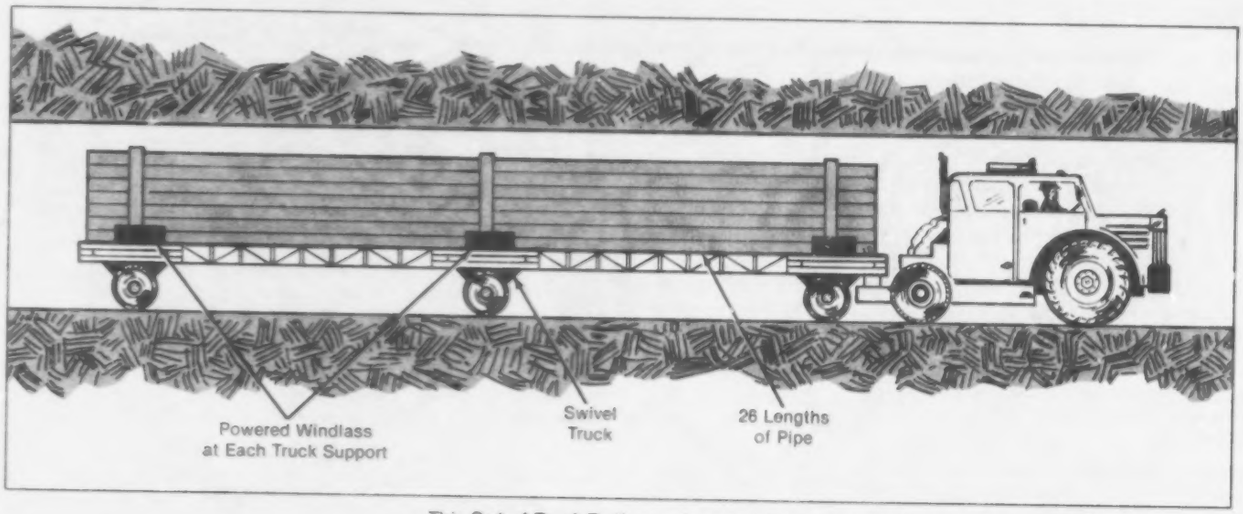


Driven by a dc motor, a **Movable Jaw** gently clamps an electronic component—in this case resistors, viewed along the axis.

Automated Conduit Unloading

Large, cumbersome pipes would be removed from a trailer by one operator.

NASA's Jet Propulsion Laboratory, Pasadena, California



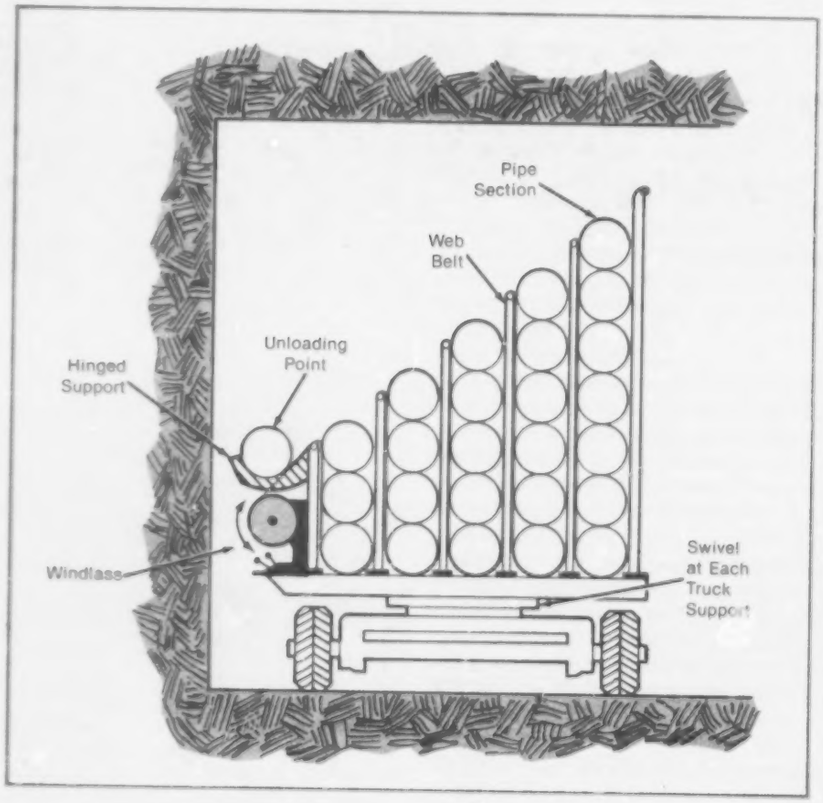
This **Swivel-Truck Trailer** carries conduit and unloads it. Vertical bins are interconnected by web belts that elevate conduit sections for delivery by gravity to the unloading point. The trailer here is loaded with slurry-pipe sections 6 inches (15.2 centimeters) in diameter, but the bin width can readily be changed to hold other sizes.

A proposed transporting and unloading apparatus would make it possible for one worker to position and connect pipe and duct sections for the hydrojet-jaw coal-mining system [see "Automated Coal-Mining System (NPO-16177) on page 128 of *NASA Tech Briefs* Vol. 9, No. 2.] The apparatus consists of a flatbed trailer equipped with vertical storage bins and three powered windlasses connected to web-belt hoists. The trailer (see figure) would carry 26 lengths of pipe or duct, each 20 feet (6.1 meters) long.

Pipe 1 moves by gravity to the unloading position, where it is held by the hinged support until it is removed for use. Thereafter, the web belt elevates pipes 2 through 26, one after the other, to a point at which they can fall by gravity into the support and fork. The movement of the pipe sections is thus achieved by continued tensioning of the belt. A clamp at the top of the partition at the left of each bin prevents the tension from acting on a pile of sections until the preceding bin has been emptied.

The same windlass and web-belt system can be used for loading the trailer. Simple adjustments in the bin-partition and web-belt positions are all that is needed to adapt the system to different conduit cross sections.

This work was done by Edward V. Lewis of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 83 on the TSP Request Card.*
NPO-16187



Oil-Free Compressor

Compressor pistons moved by an eccentric shaft need no lubricants.

Lyndon B. Johnson Space Center, Houston, Texas

Originally proposed for use in space, a new compressor for refrigerators or freezers does not depend on a pool of oil for lubricating its pistons. It can thus be operated in any orientation.

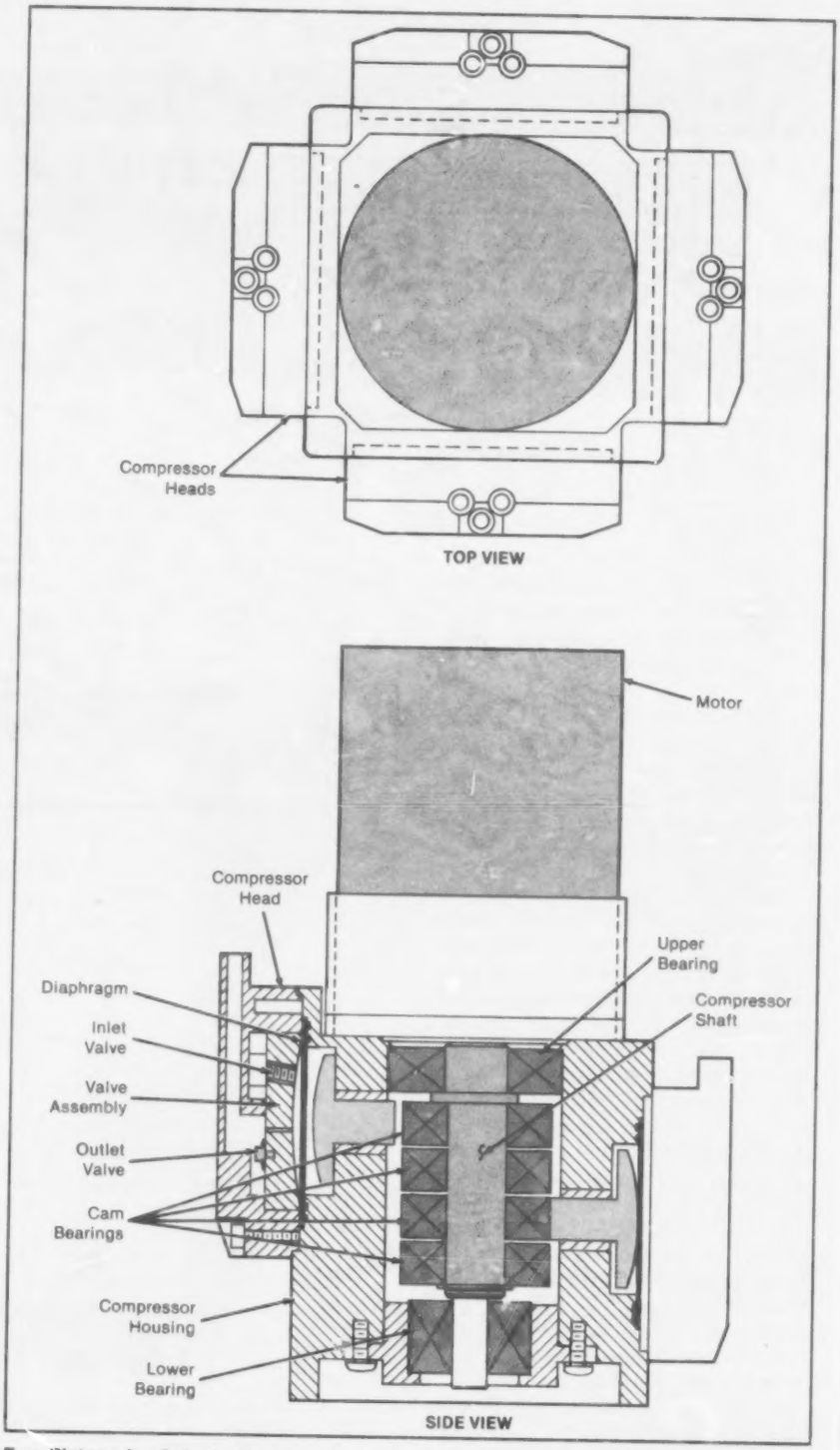
The compressor has a shaft, the middle section of which is eccentric in relation to the end sections (see figure). Driven by a brushless dc motor, the shaft turns the inner races of a set of four cam bearings. The outer cam-bearing races in turn actuate four pistons spaced equally apart, around and along the shaft. Each outer bearing race is held in position by the pressure exerted on it by the piston. Because there is no frictional motion between the piston and the outer bearing race, lubricant between them is unnecessary. The cam bearings themselves contain a potted internal lubricant.

The movement of the outer races of the cam bearings moves the pistons radially in and out. When the piston moves out, its domed head pushes a diaphragm into a dome-shaped chamber, thereby compressing the refrigerant in the chamber. Further rotation of the eccentric shaft removes the outward force on the piston. The pressure of the refrigerant on the diaphragm then pushes the piston radially back to its starting position.

Each dome-shaped compression chamber contains a one-way inlet valve and a one-way outlet valve. The inlet valve opens to admit refrigerant to the chamber as the piston moves away from the diaphragm and closes as compression begins. The outlet valve opens to release the compressed refrigerant and closes at the end of the compression stroke. Commercially available cylinder heads house the four valve assemblies; the four pistons are also commercial items.

The diaphragms are flat, round elastomer sheets. The elastomer is selected for chemical compatibility with the refrigerant. The compressor housing is machined from a solid piece of aluminum. It can be designed for two, three, or more than the four pistons illustrated, depending on the required system cooling capacity.

This work was done by D. G. Fitzjerrell, T. L. Belver, and H. E. Moore of Management and Technical Services Co. (a subsidiary of General Electric Co.) for **Johnson Space Center.**



Four Pistons Are Actuated in sequence by the eccentric compressor shaft. Two of the pistons are shown in the cross section.

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the Management and Technical Services Co., Houston, TX 77058. MSC-20860

Pressure-Letdown Machine for a Coal Reactor

Pumps operating in reverse can generate power.

NASA's Jet Propulsion Laboratory, Pasadena, California

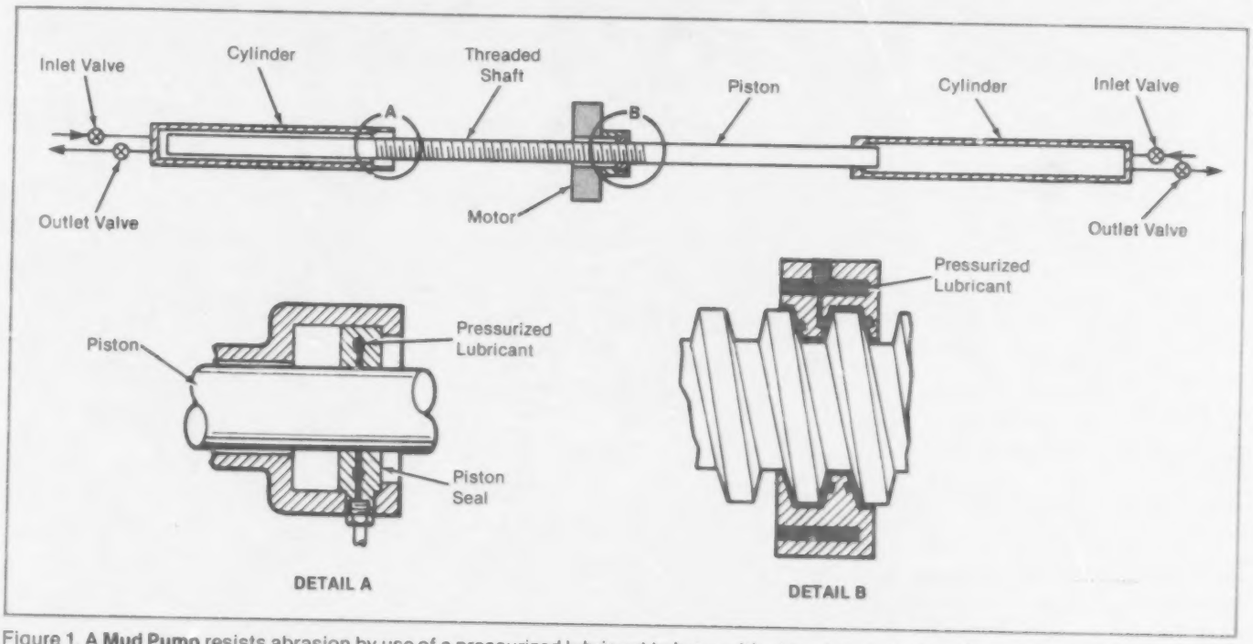


Figure 1. **A Mud Pump** resists abrasion by use of a pressurized lubricant to keep critical mating parts clean. The pump would be operated in reverse, using the expansion of the pressurized coal-liquefaction product to generate power.

A conceptual pressure-letdown machine for a coal-liquefaction system can extract energy from the expansion of the product fluid. Mud pumps, originally intended for use in oil drilling, would be operated in reverse so that their motors would act as generators. Several pumps could be operated in alternating phase to obtain multiple stages of letdown from the inlet pressure [typically 2,000 psi (14 MPa)] to the outlet pressure [typically 100 psi (0.7 MPa)]. About 75 percent of the work that generates the inlet pressure should be recoverable as electrical energy.

The mud pump (see Figure 1) includes two opposed cylinders with pistons on a slowly-reciprocating common shaft. A nut rides on the threaded middle portion of the shaft to couple the motor to the shaft, converting the rotational motor power to axial shaft power, or vice versa.

The piston seals and the threaded nut/shaft interface are lubricated by cleaned pressurized product fluid. As the fluid seeps out, it washes the pistons and the threaded surfaces. This washing action makes the pump resistant to abrasion by oil-drilling mud and is expected to help it withstand abrasion by the coal-liquefaction product.

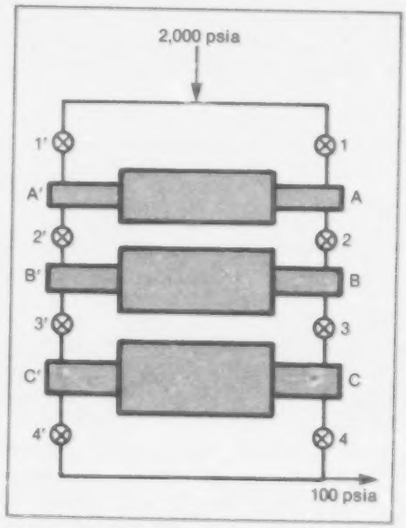


Figure 2. **A Triple-Expansion, Pressure-Letdown System** uses mud pumps and synchronized control valves. Each stage is larger than the preceding one to allow for expansion.

Figure 2 illustrates a triple-expansion scheme that uses three pumps, the motions of which are synchronized through valve controls. Valves 1 and 1′ are connected to the high-pressure inlet. Valves 1 and 1′ are controlled so that one is open while the other is closed, or vice versa, except during part of the expansion phase of each cycle. Valve sets 2 and 2′ and 3 and 3′ are similarly controlled. All valve openings and closings are made when the pressure differentials across the affected valves are near zero, and product expansion across the valves is minimized.

If the piston in cylinder A is at the right end, valves 2 and 1′ are closed, while valves 1 and 2′ are open. Pressurized fluid enters cylinder A, driving its piston toward the left. The piston in cylinder A′

pushes the fluid out of that cylinder, through valve 2, and into cylinder B′. When the piston has moved a prescribed distance, valve 1 closes, and the piston continues to move as gas is released from the high-pressure fluid.

When the piston reaches the left end of its stroke, valve 2′ closes, and valves 1′ and 2 open. Pressurized fluid then flows through valve 1′ into cylinder A′, the shaft moves to the right, and piston A forces its fluid out through valve 2 into cylinder B.

The subsequent stages operate similarly, driven by the expanded fluid from the preceding stages. To accommodate the expansion, the cylinders of each stage are larger than those of the previous stage. The last stage is connected through valves 4 and 4′ to a single outlet pipe, so that the pipe is always receiving fluid at the third-stage pressure from one side or the other.

This work is done by Gerald S. Perkins and William B. Mabe of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 84 on the TSP Request Card. NPO-15083*

Helicopter Tail-Boom Strakes

Yaw control and overall efficiency are increased at hover and low speeds.

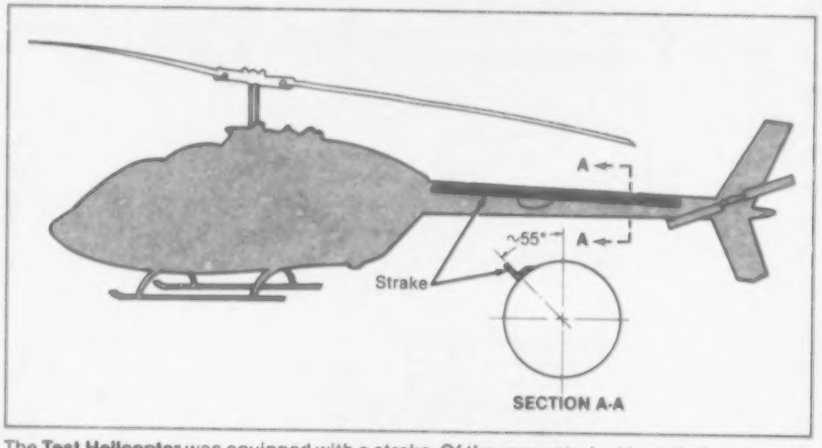
Langley Research Center, Hampton, Virginia

Wind-tunnel tests in the Langley Research Center 4- by 7-Meter Tunnel indicated that flow over the tail boom induced by the main rotor wake and by sideward and yawing flight can result in high side loads on helicopter tail booms. Also, the tunnel investigation showed that a strake located on the left side of the tail boom has the potential to reduce the high adverse side loads on a tail boom in hover and in sideward flight. A reduction in the adverse side loading on the boom, in turn, would result in a reduction in the tail-rotor thrust required for trim. Also, recent preliminary flight results obtained by the U.S. Navy Flight Test Center indicated that a strake located on the left side of the boom of a medium-size helicopter substantially increased the right sideward speeds obtainable.

The current work investigated the potential effectiveness of simple strakes on the tail boom of a lightweight Army helicopter in increasing the yaw-control pedal-position margin in right sideward flight and in reducing the effects of the tail-rotor vortex-ring state during left sideward flight. Several strake designs were evaluated in flight to determine the most effective design and to define potential benefits and problems. It was recognized that the effects of tail-boom forces and moments were likely to be only a part of the directional-control problem of the test helicopter.

The flight investigation was conducted at the Applied Technology Laboratory, Fort Eustis, Virginia. The figure shows the helicopter used in these tests with a strake installed. Onboard instrumentation measured the pedal position and angular yawing velocity, both of which were recorded on a tape recorder. A ground pace vehicle equipped with a calibrated fifth wheel provided an accurate measure of ground speed.

The aircraft speed was maintained through the use of a pace vehicle for speeds of 0 to 35 kn (0 to 18 m/s) in increments of 5 kn (2.6 m/s). Several azimuth angles were investigated with emphasis on left and right sideward flight. Aircraft and meteorological parameters were monitored closely to ensure data quality.



The Test Helicopter was equipped with a strake. Of the many straked installations tested, this one was the most effective.

Test results demonstrated that the addition of a single long strake to the left side of the tail boom was the most effective configuration for reducing left pedal requirements in right sideward flight [5 to 6 percent of the total pedal range at 33 kn (17 m/s)]. Much larger reductions in pedal are expected on more heavily loaded helicopters and helicopters with tail-boom cross-sectional shapes that would yield larger side forces. Strakes on the boom did little to reduce the unsteady effects in the tail-rotor vortex-ring state and usually resulted in a minor shift in the velocity range over which it occurred [12 to 25 kn (6 to 13 m/s) left]. With strakes on or off, rapid and large changes in the static-directional stability (stable to unstable) in the vortex-ring state [left sideward flight 15 to 20 kn (8 to 10 m/s)] can occur and contribute to the control problems experienced in this flight regime.

Since a strake placed on one side of the tail boom will also give rise to new forces for other flight conditions and will act as a lifting surface producing additional effects, the strake may be designed to be retractable when not in use to avoid any undesirable effects. Flight-test data obtained at Fort Eustis verified the trends observed in the Langley wind-tunnel tests.

For U.S.-built helicopters, the strakes would be mounted on the upper left side of the boom. For helicopters with rotors turning in the opposite direction, the strakes would be placed on the upper right side of the boom.

This work was done by Henry L. Kelley, Arthur E. Phelps III, and John C. Wilson of the U.S. Army Aerostructures Directorate located at the **Langley Research Center.** *For further information, Circle 3 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13233.

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Air-Bearing Table for Machine Shops

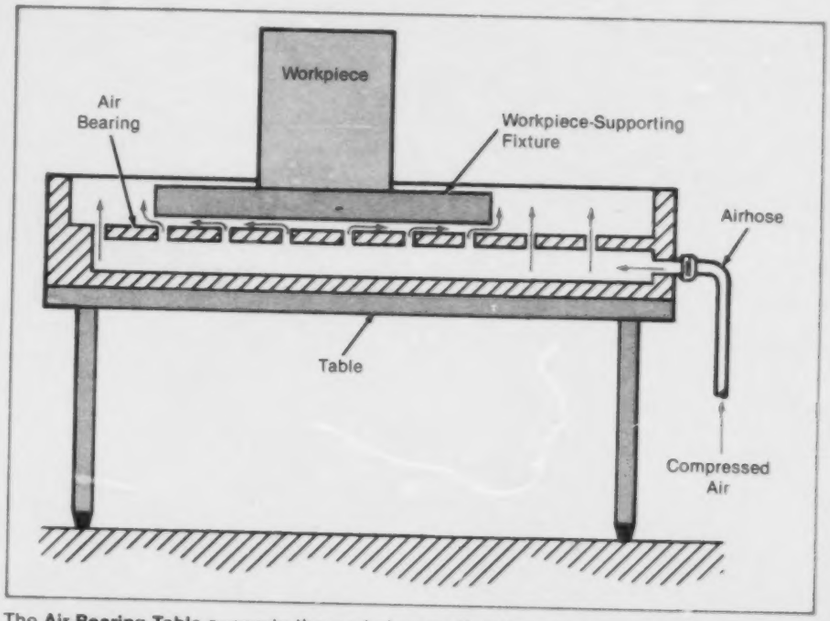
Frequent workpiece repositioning is made easier.

Marshall Space Flight Center, Alabama

An air-bearing table facilitates the movement of a heavy workpiece during machining or between repeated operations at different positions. The table assembly consists of a workpiece-supporting fixture riding on an air bearing. The table is especially useful for inertia welding, in which the ease of mobility is important.

As shown in the figure, compressed air is fed to a plenum, from which it escapes through small holes in the table surface. A low-friction air cushion is thus formed under the workpiece-supporting fixture: This enables the fixture to slide easily over the table, even when bearing a heavy workpiece.

This work was done by Don Ambrisco of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29035



The **Air-Bearing Table** supports the workpiece so that it can be moved easily.

Electromechanical Turboprop-Pitch-Control Mechanism

The propeller-control system is autonomous and tolerant of failure.

Lewis Research Center, Cleveland, Ohio

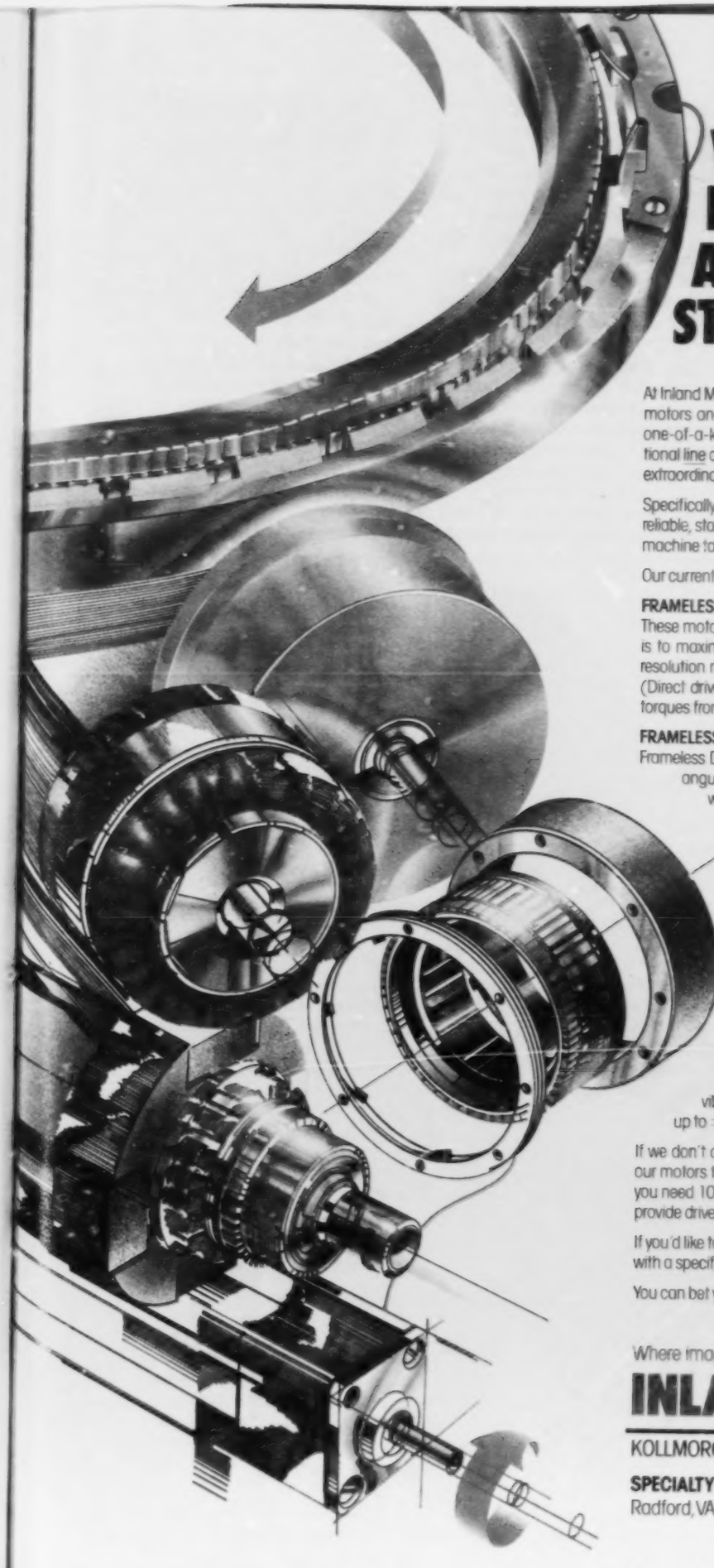
An advanced autonomous electromechanical turboprop-pitch-control mechanism has been designed that meets the demanding requirements of a high-power advanced turboprop. Although propeller-driven aircraft have flown successfully for over 70 years, the exceptionally-large blade torques and synchrophasing requirements of future turboprop aircraft, with blade diameters up to 13 ft (4 m) necessitate the use of advanced propeller-pitch-control mechanisms (PCM's).

The electromechanical PCM pitch-control mechanism described here (see figure) represents a significant improvement in the accuracy, reliability, and maintainability of state-of-the-art, hydraulically-controlled propeller systems. This system takes maximum advantage of recent advances in electric-motor, fiber-optic, mechanical-drive-system, and digital-control technologies. Mounting the electrical-power module and conditioning/control systems inboard the rotating propeller hub eliminates failure-prone slipring devices and creates an autonomous, failure-tolerant propeller-control system. Modular component design facilitates on-the-wing maintenance. The system is highly adaptive to various sizes and gearbox configurations.

The features and capabilities described are unmatched by any comparable PCM now in existence. These capabilities will be needed by large, fuel-efficient, commuter turboprop aircraft now being developed by the aircraft industry.

The all-electromechanical PCM system accurately controls the propeller-blade angle of large (10,000-kW) turboprop-aircraft propellers over a wide spectrum of flight operating conditions. The PCM is housed within the propeller hub, as illustrated in the figure. The system is appropriate for 150-passenger, advanced turboprop commuter aircraft that cruise at mach numbers between 0.7 and 0.8. An autonomous, solid-state digital-control module, located in the nose of the spinner for ease of maintenance, commands blade-angle position based on digital control-signal information passed from the cockpit. These control-signal data are optically encoded and passed across the rotating interface through a fiber-optic data link (rotary coupling) having superior noise rejection and data bandwidth characteristics.

The autonomous electronic-control module onboard the spinner contains sufficient internal logic to maintain normal, constant propeller-speed operation in the event of a failure of the fiber-optic data



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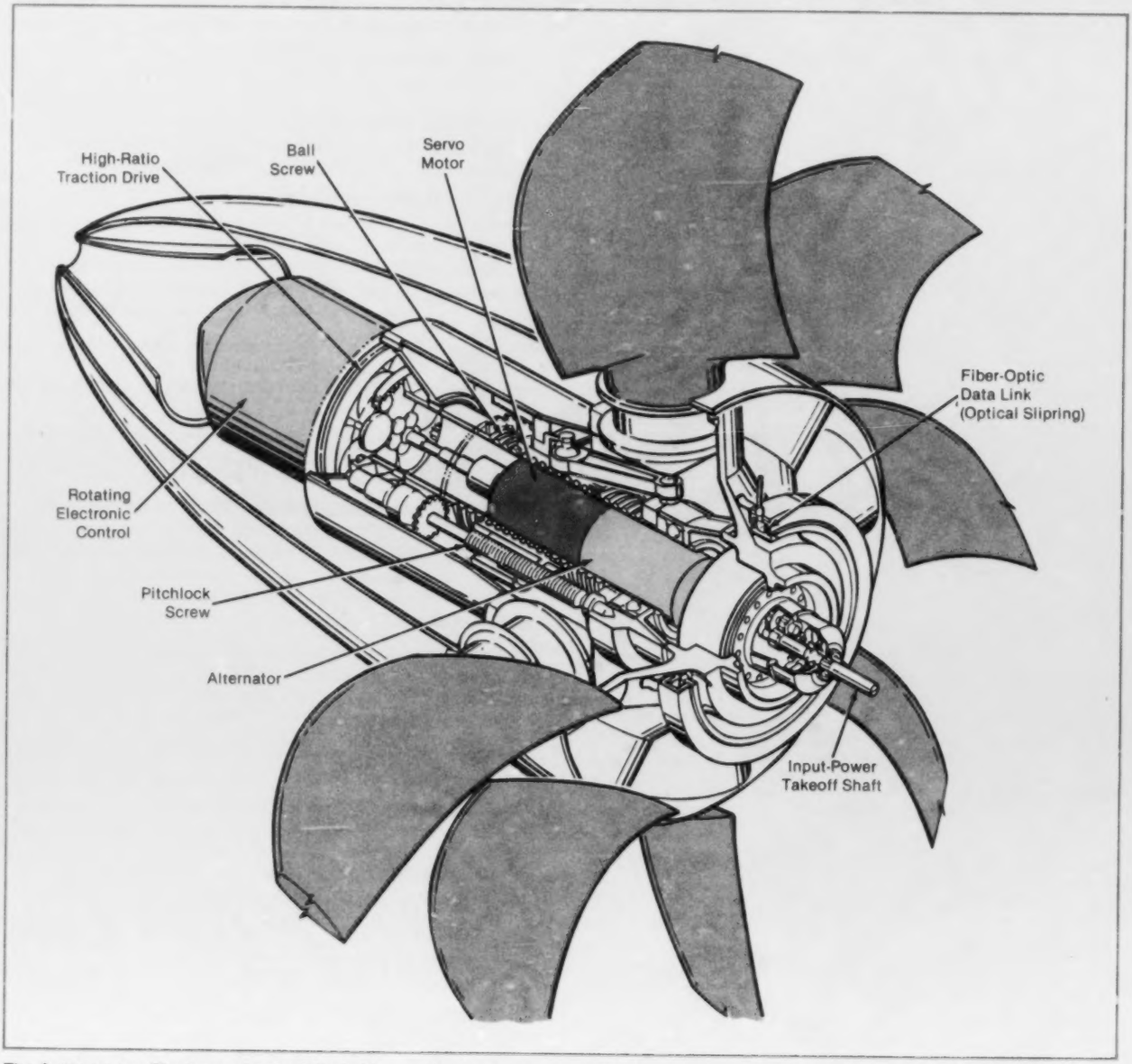
link. A high-power-density, high-speed (20,000-rpm), electronically-commutated, permanent-magnet (PM) synchronous motor located within the rotating spinner provides the mechanical power to change blade angle. Electrical power for this motor is generated onboard the rotating spinner by a similarly-constructed PM synchronous alternator colocated with the motor on the centerline of the propeller hub. Mechanical power to drive this alternator is shipped across the rotating interface from a power takeoff shaft extending from the main propeller gearbox. This arrangement eliminates the need for high-maintenance, rotating power-transfer devices, such as electrical-power sliprings or hydraulic-fluid-transfer seals (in the case of hydraulic actuators).

The servocontrol motor is mechanically coupled to the blades through an 8,000-to-1 reduction drive train, effecting a maximum blade slew rate of 15°/s for emergency feather and reverse-thrust operation. Since cruise occupies the bulk of the mission, the drive mechanism normally is functioning in a low-speed, hunting mode (blade slew rates from 0° to 1°) to achieve synchrophasing. (Synchrophasing may be defined as the synchronization of multiple engine-blade positions to minimize the annoying "beating" noise.) The drive mechanism consists of a torsionally-stiff, low-loss hybrid traction drive, which couples the motor to a ball screw. The ball screw, in turn, articulates the individual blades through stiff links, connected at one end to an eccentric pin at the blade root and at the other end to the translating ball-screw nut. Blade-angle settings typically range from about −7° at maximum reverse pitch to +85° at flight feather.

In the event of any mechanical or electrical component failure, the system is also equipped with an independently-driven, emergency pitch-lock screw mechanism, which tracks the current position of the ball-screw nut and will lock the blades within approximately 1° of their last position. This required safety feature eliminates any danger of propeller overspeeding and allows engine operation in the "fixed-prop" mode.

Blade-position accuracies are within 3 arc-minutes of a degree for the system described. The three primary factors that contribute to this precision are the digital electronic feedback control system, the programable servocontrol motor, and the torsionally-stiff, low-hysteresis mechanical drive mechanisms.



The **Autonomous Electromechanical Pitch-Change Mechanism** accurately controls propeller-blade angles on large (10,000-kW) aircraft engines. Modular component design facilitates maintenance.

In comparison with current hydraulic-control systems, the electromechanical PCM described here will reduce estimated maintenance costs by 9 percent, reduce weight by 5 percent, and increase mean time between all maintenance actions from the current 2,700 hours to 3,250 hours. Other identifiable benefits with the proposed electromechanical PCM include the following:

- The elimination of high-maintenance, high-pressure hydraulic pumps and motors;
- Inherent compatibility between the brushless PCM servomotor and electronic digital controls; and
- The elimination of the PCM oil-lubrication system with greased, packed motor/generator bearings, linkage joints, ball screw, and traction roller-drive module.

This work was done by B. M. Steinetz and S. Lowenthal of **Lewis Research Center,** *D. F. Sargisson of General Electric Co., and G. White of Transmission Research, Inc. Further information may be found in NASA TM-83709 [N84-25605/NSP], "An Advanced Pitch Change Mechanism Incorporating a Hybrid Traction Drive" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. LEW-14234*

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Operating a Remote Manipulator in Simulated Low Gravity

A microgravity simulator shows that control is adversely affected, but compensation is possible.

Efforts to control remote manipulators in simulated microgravity are described in a report. The experiments were conducted to determine the effects of weightlessness on the performance of an operator controlling a remote manipulator, or slave arm, by a master arm at a control station.

A six-dimensional force-reflecting hand controller was used as the master arm. With this controller, the operator's hand and arm movements are translated into movements of the remote manipulator. Through the hand controller, the manipulator feeds back to the operator sensory information about the forces acting on it.

A gravity-compensation support for the operator's upper arm and hand simulated the nearly zero gravity that would prevail in a space station in Earth orbit. The support provided a constant force at the center of mass of each limb segment. The force was equal and opposite to the gravitational force acting on the segment. The forces were furnished by low-inertia, constant-tension springs that are adjustable to the body characteristics of the individual operator.

An operator's performance using the hand controller with the support was compared with the same operator's performance with the support. In general, operators were less accurate with the support—that is, in simulated microgravity—than in normal gravity.

The report concludes that microgravity disturbs neuromotor control of the human arm. It also suggests that the disturbance can be compensated for by adjustments in the controller.

This work was done by Antal K. Bejczy and Kevin M. Corker of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Experiments in Simulated Microgravity of Manual Control of Teleoperators," Circle 16 on the TSP Request Card. NPO-16477*

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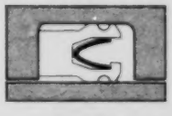

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Hardware, Techniques, and Processes

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140 Thermoplastic Composites for Research-Model Components
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Books & Reports

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Ion-Deposited Polished Coatings

Polished, dense, adherent coatings are relatively free of imperfections.

Lewis Research Center, Cleveland, Ohio

A process has been developed to provide a highly-polished and adherent dense coating to a substrate that is free of voids, contaminants, and inclusions. A broad-beam ion source is used to sputter-polish while a vapor or sputter deposition is occurring simultaneously on the substrate surface. Prior techniques removed material from the surface, exposing subsurface voids and contaminants. No simultaneous fill of voids occurred and therefore the surface was not free of defects since these were removal processes.

The new process consists of using a broad-beam ion source in an evacuated chamber to ion-clean a rotating surface that allows the grazing incidence of the ion beam. This sputter cleans off absorbed gases, organic contaminants, and oxides of the mirror surface. In addition to the cleaning, surface protrusions will be sputter-etched away.

Once the surface has been ion-cleaned, a variety of vacuum-deposition techniques can be used to deposit adherent coatings on the cleaned mirror surface. Figure 1 depicts grazing-incidence ion polishing with simultaneous, normally incident vapor or sputter deposition. The simultaneous sputter polishing and vacuum deposition must be done in a manner so that the sputter-etch rate is slightly lower than the deposition rate on the mirror surface. This allows pits or depressions in the mirror surface to fill in quickly because the grazing-incident ion beam does not have a view factor to sputter-etch these areas which are receiving near-normal incident vapor or sputter deposition. At the same time, protrusions, bumps, and other convex surface asperities have a sputter-etch rate higher than surrounding smooth flat surfaces. This is due to the relative angles at which the sputter-etching ions and the deposition material arrive.

Figure 2 depicts the processes of simultaneous ion sputter, polishing, and deposition. The process leads to a smooth deposited and polished surface in a similar manner analogous to the macroscopic process of multiple painting and sanding operations for wood finishing. The net deposition resulting quickly becomes a smooth mirror-surface deposit that slowly builds up free from surface irregularities, such as defects, voids, or protrusions. The process is stopped when the desired deposit thickness is achieved. Both the ion-beam sputter polishing and the deposition should be stopped simultaneously when the desired coating thickness is achieved.

Eleven other adaptations to the process are the following:

1. The mirror material can be metals, metal carbides, metal oxides, certain polymers, and most inorganic compounds.
2. The deposition can be produced by vapor deposition from electron-

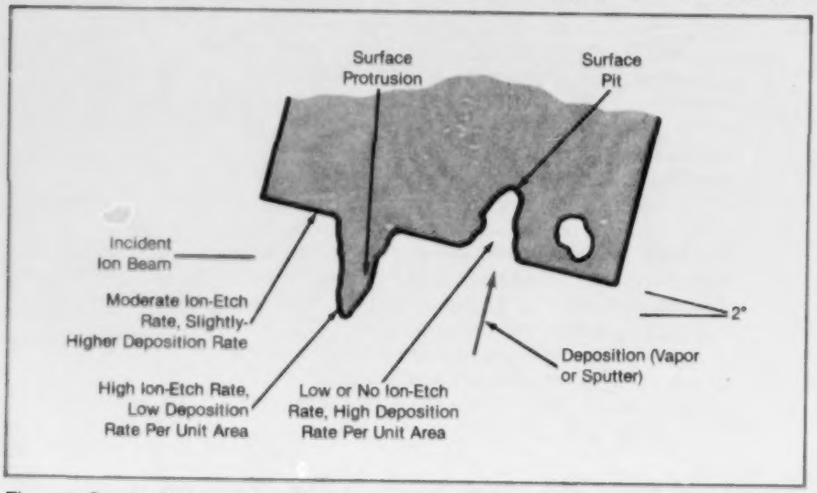

Surface Protrusion
Surface Pit
Incident Ion Beam
Moderate Ion-Etch Rate, Slightly-Higher Deposition Rate
2°
Deposition (Vapor or Sputter)
High Ion-Etch Rate, Low Deposition Rate Per Unit Area
Low or No Ion-Etch Rate, High Deposition Rate Per Unit Area

Figure 1. **Grazing-Incidence Ion Polishing** is conducted simultaneously with deposition by normally incident vapor or a sputtering beam.

beam evaporators, heated boats, filaments, or by ion-beam, dc or RF sputtering from the same or another deposition system.

3. The substrate surface angle θ can be varied from 0° to ≅ 10° with respect to the incident ions, depending on the degree of polishing desired.
4. The surface can be cooled or heated as desired to improve the quality of the coating.
5. The ion energy can be varied from a few hundred to a few thousand electronvolts.
6. The sputtering ions can be a variety of gas species, such as Ar, Xe, Ne, and N.
7. The duration of initial sputter-etch cleaning can be varied from seconds to hours, depending upon the thickness desired.
8. The ion beam can be of various diameters, from centimeters to meters, depending upon the substrate diameter.
9. The deposited coating can be a variety of materials, such as metals, metal oxides, and metal nitrides. The deposited materials can also be a different material than the substrate.
10. The rotation rate of the substrate can be varied as desired to produce the best-quality surface coating.
11. Further coatings can be applied by the same process if one wants to switch materials for the outer substrate surface.

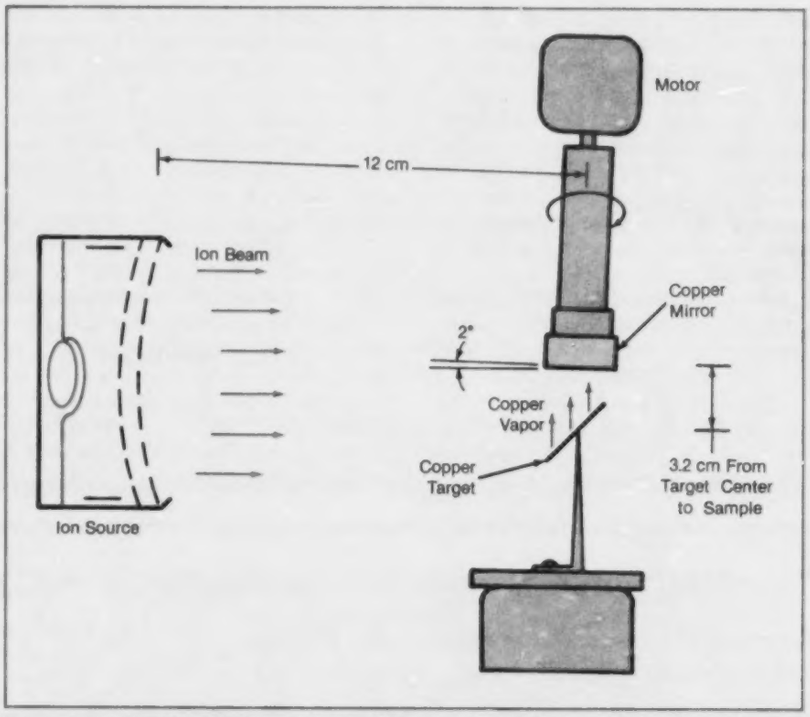


Figure 2. **Ion Sputter Polishing** and deposition give a smooth deposited and polished surface, in a manner analogous to that of the repeated painting and sanding of wood.

The process is particularly adaptable to the polishing of various substrates for optical or esthetic purposes.

This work was done by Bruce A. Banks of **Lewis Research Center.** *Further information may be found in NASA TM-81679 [N81-19278/NSP], "Simultaneous Ion Sputter Polishing and Deposition" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.* *LEW-13545*

Heat Bonding of Irradiated Ethylene Vinyl Acetate

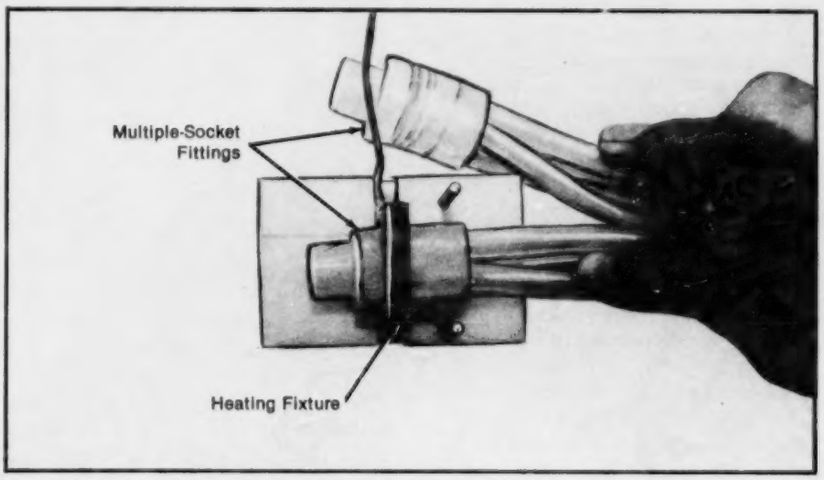
A reliable method is now available for joining parts of this difficult-to-bond material.

Lyndon B. Johnson Space Center, Houston, Texas

Tubing and fittings of irradiated ethylene vinyl acetate (EVA) are joined to each other with a new heat-bonding technique to form reliable, leak-free junctions. EVA tubing is useful as a conduit for cooling water because contaminants are not leached out of it by the water. The use of EVA was previously inhibited by the difficulty of joining this material to itself.

The new technique takes advantage of a characteristic of irradiated EVA: the migration of residual non-cross-linked oligomers to the surface when heated. The resulting exudate is tacky while hot. When a tube and socket are put together and heated, the exudate from the heated tubing mingles with that from the socket and forms a bond upon cooling.

The first step in the bonding process



A **Heating Fixture** encircles an ethylene vinyl acetate multiple-socket part, providing heat to it and to the tubes inserted in it. Fixtures are specially designed to match the parts to be bonded.

is to cut the tube end perpendicularly to the bore. The end is then cleaned with acetone and inserted in the socket. [If the tubing has a diameter less than one-eighth inch (about 3 millimeters), a stiffener, such as polytetrafluoroethylene-coated wire, will prevent the tube from distorting or collapsing.] A heating fixture, specially shaped to conform to the parts, is installed around the area to be heated (see figure).

Power is applied to the heating fixture while its temperature is monitored with thermocouples. The bond area is heated to 220 °F (104 °C) and held there for 4 minutes. The parts are allowed to cool naturally for 3 minutes and are then further cooled by forced air. The assembly can be handled when the temperature drops below 113 °F (45 °C) since the bond will then have been formed. Stiffeners, if used, are removed at that point.

An important advantage of the method is that a joint can be separated and rebonded. The heating fixture is placed over the joint and heated gradually toward 400 °F (204 °C). Starting at 350 °F (177 °C) and while the temperature continues to rise, the tube is alternately stretched and released until it peels away from the socket. As soon as the tube is removed, a sizing tool is inserted in the socket to maintain its shape as it cools. Meanwhile, the tube is heated briefly so that it resumes its original shape. The tube and socket are then ready for rebonding.

The surfaces of the copper heating fixture must be treated before use with a high-temperature mold release to prevent sticking. If sticking occurs in spite of this precaution, the tool should be reheated to soften the EVA surface. When the fixture is removed in this way, however, it does not leave a smooth surface.

Tube-and-socket bonds made with this technique were subjected to tensile tests. Bond strengths of 50 percent that of the base material were obtained consistently.

This work was done by David H. Slack of ILC Dover for **Johnson Space Center.** *For further information, Circle 68 on the TSP Request Card.*
MSC-20320

Thermoplastic Composites for Research-Model Components

Oriented unidirectional prepreg tapes are formed in ceramic molds.

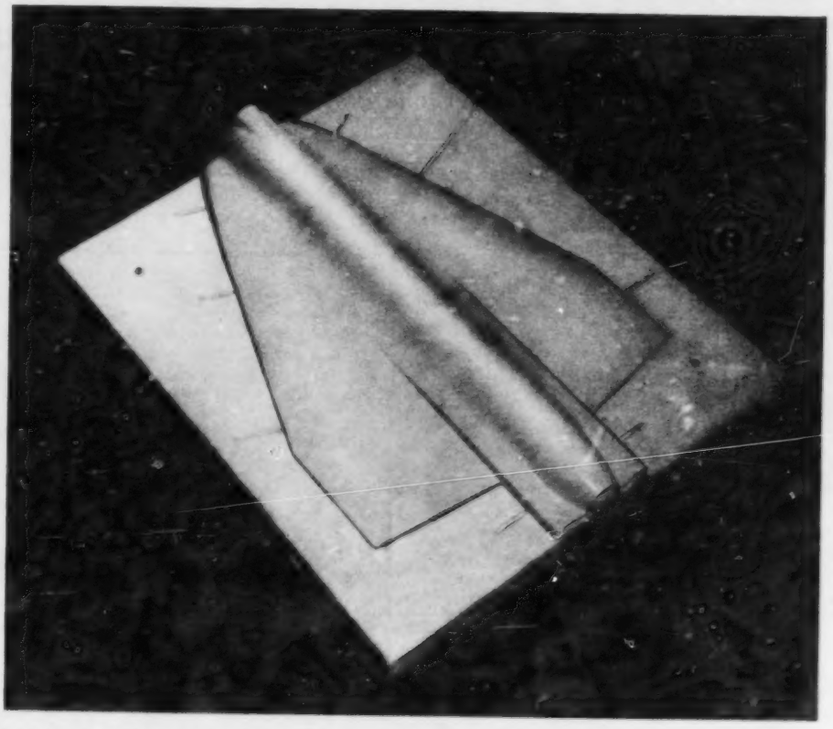
Langley Research Center, Hampton, Virginia

The construction of stiffer aircraft structures generally results from the use of graphite/epoxy or graphite/thermoplastic composites. Advanced wing designs take advantage of this stiffness by tailoring ply layup and ply orientation. To obtain the same scale effect in the construction of research models, the same materials must be used that are being developed for full-scale aircraft. Composite materials of graphite/epoxy are already being used in model fabrication. A new technique has been developed at Langley Research Center, using a ceramic mold for the fabrication of models from graphite/thermoplastic materials.

The remelt capability of thermoplastics allowed the proper ply orientation of the unidirectional graphite. The prepregs were tacked together during layup with a soldering iron, thus ensuring the desired ply orientation during the curing cycle. Ceramic materials were used for the mold because they can withstand the high temperatures and pressures of the thermoplastic-resin curing cycle and can be fabricated more quickly and economically than metal molds.

The upper surface of a model, which includes the wings and fuselage of an advanced fighter aircraft, was selected to be fabricated from the thermoplastic preimpregnated material and to be used as the mold pattern (see figure). The unidirectional, continuous-filament graphite material was preimpregnated with a high-temperature thermoplastic resin. The layup method involved preforming the shape to minimize bulk, thereby allowing the fiber orientation to remain constant and preventing excessive pressure on the molds.

The correct length of prepreg was stripped, inserted manually into the mold, and successive strips were tacked together to acquire the shape of the mold and, ultimately, the component.



The Upper Surface of the Wings and Fuselage of an advanced airplane was selected as a shape to test the fabrication technique. The technique is well suited for other complex shapes as well.

This layup method is vital in the fabrication of complexly shaped pieces. Each layer of an eight-ply layup was made in this manner. A quasi-isotropic layup equal in all four directions was selected for tests (0°, 90°, ±45°, ±45°, 90°, 0°).

The ceramic mold was preheated to 800 °F (430 °C), then opened, and the preformed layup was placed between the mold halves. The mold was then closed and placed in a heated press. A thermocouple attached to the mold recorded the temperature. Once the mold reached 800 °F (430 °C), a pressure of 700 psi (4.8 MN/m^2) was applied for 10 min. The press was allowed to cool under pressure till it reached 700 °F (370 °C), at which point the pressure was gradually reduced.

The component was removed when the press reached room temperature. The thermoplastic composite was found to be easily workable with normal shop equipment and could be painted and repaired by all of the standard methods.

This work was done by Benjamin F. Guenther and Peter Vasquez of **Langley Research Center.** *No further documentation is available.* *LAR-13348*

Controlling Arc Length in Plasma Welding

A circuit maintains the arc length on irregularly shaped workpieces.

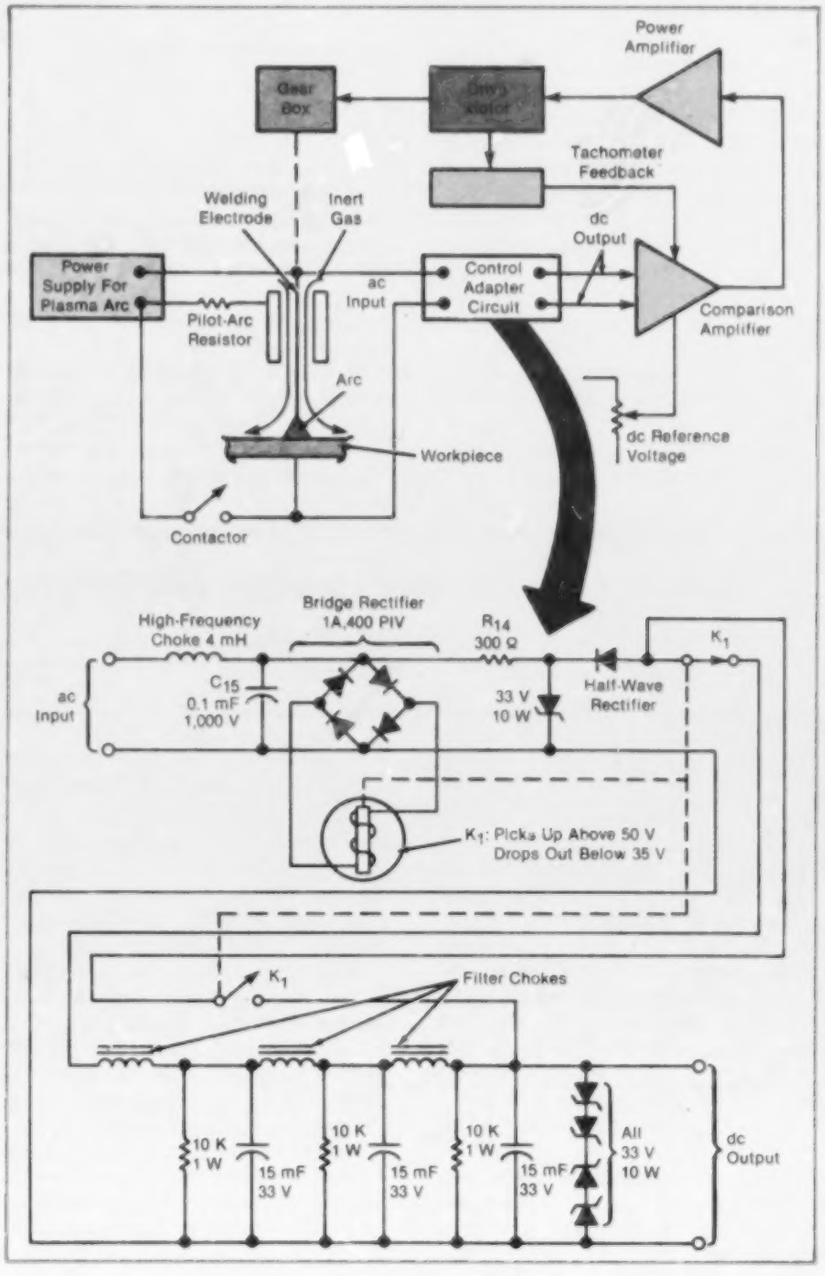
Lyndon B. Johnson Space Center, Houston, Texas

A control adapter circuit maintains a constant arc length during plasma arc welding of irregularly contoured parts. The circuit can be added to plasma arc welding machines with just a few wiring changes. Welds made with the circuit are cleaner and require less rework than do welds made without it. The beads are smooth and free of inclusions.

The circuit (see figure) samples the ac arc voltage, then half-wave rectifies and filters it to reduce the ripple. The resulting dc measurement signal is applied to a comparison amplifier, which compares it to a reference voltage that represents the commanded arc length. The amplified comparison signal is applied to a power amplifier that drives a motor and gear train to adjust the electrode position and therefore the arc length.

This work was done by William F. Iceland of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 66 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20900.



The **Length of a Plasma Arc** is continuously adjusted by the control circuit to maintain the commanded value. After a pilot arc has been established, the contactor is closed and transfers the arc to the workpiece. The control circuit then half-wave rectifies the ac arc voltage to produce a dc control signal proportional to the arc length.

Optical Monitoring of Weld Penetration

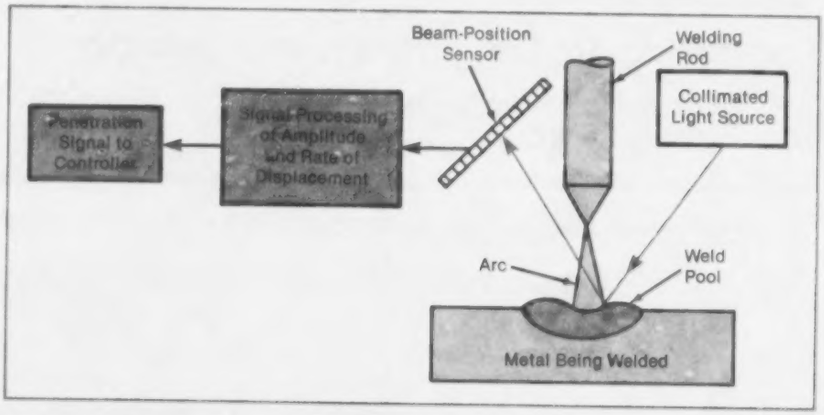
Robotic welding can be controlled by a reliable, relatively-noise-free optoelectronic unit.

Marshall Space Flight Center, Alabama

A system is being developed to monitor weld penetration optically and produce a signal for controlling an arc welder. The system is aimed for automatic welders, robot welders in particular. Made from small, low-cost components and utilizing optical fibers to conduct the signals, the system is immune to the electromagnetic interference that is common in industrial environments.

The monitor directs collimated light from a small diode laser at the molten pool of metal beneath the arc (see figure). A filter intercepts the reflected beam to suppress extraneous light, including light from the welding arc. A position-sensitive detector at a distance from the pool intercepts the beam reflected by the pool.

If the weld penetrates the workpiece completely, the curvature of the pool surface suddenly changes. This causes a sudden deflection of the reflected light beam, and consequently a displacement of the beam spot on the detector. Signal-processing circuitry determines the amplitude and rate of beam displacement to detect penetration and to generate control signals for the robot to regulate welding parameters.



Bounding Off the Meniscus of a Pool of Molten Metal, a laser beam impinges on a position-sensitive photodetector. The beam diameter can be adjusted for the width of the weld. Optical filters screen out the light from the arc.

The monitor is insensitive to changes in weld current, welder speed, and the thermal properties of the welded metal except as they affect weld penetration. The monitoring principle is adaptable to other types of welding, including tungsten/inert-gas, laser, and electron-beam techniques.

This work was done by Jonathan Maram of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29107

Crystal-Growing Crucible To Suppress Convection

A platform under the growth region can stabilize the melt for a more uniform crystal growth.

NASA's Jet Propulsion Laboratory, Pasadena, California

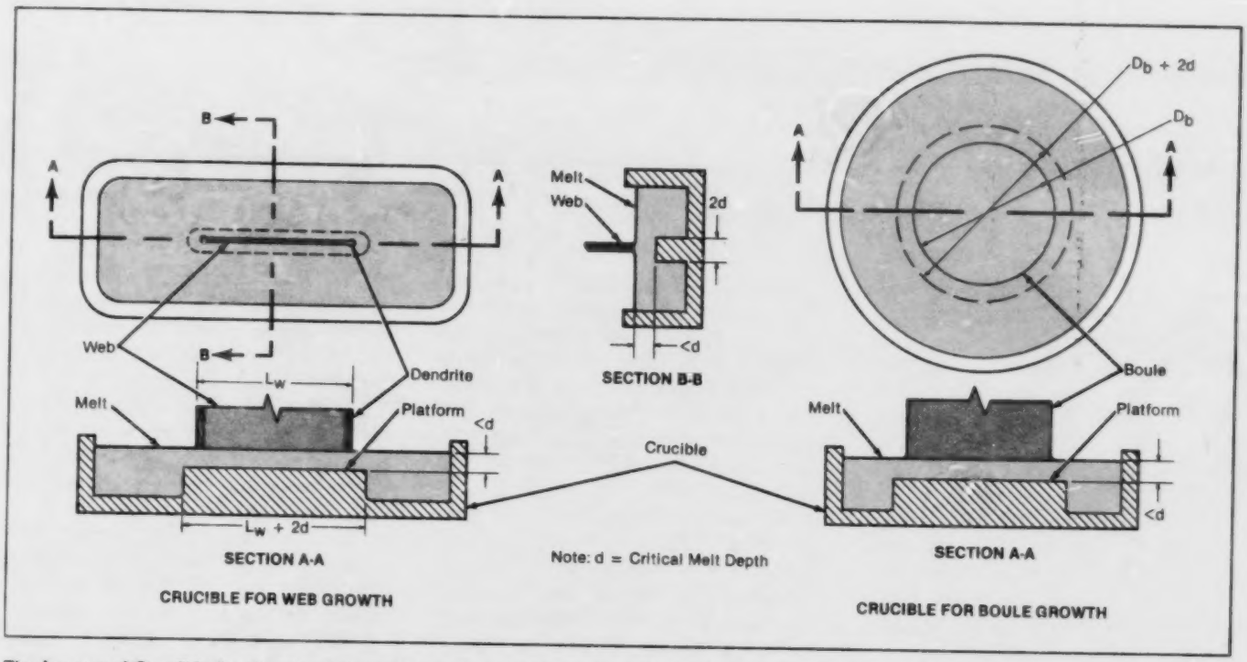
A proposed crucible for growing silicon webs or boules can suppress thermal convection near the solidification interface. Thermal convection must be suppressed because it causes nonuniform crystal growth. In the new crucible (see figure), there would be a platform just below the growth interface so that the melt would be too shallow to support convection.

The new crucible design is derived from the theory of stability of a heated fluid. The instabilities that give rise to convection occur when the gravitational forces due to thermally induced density gradients exceed frictional forces in the fluid. The critical depth for the onset of the pertinent instability can be calculated from the heat flux through the surface of the melt, the volume coefficient of thermal expansion, the thermal conductivity, the thermal diffusivity, and the kinematic viscosity.

All of these quantities except the heat flux are properties of the molten material and are available in standard reference works. The heat flux can be evaluated in terms of the system configuration and operating conditions. For example, if the crucible operates in a vacuum, the heat flux equals the net thermal radiation from the melt surface. If the operation is in a gaseous environment, conduction and convection also contribute to the heat flux.

The width of the platform is approximately the width of the crystal plus twice the critical depth. The platform height is such that the melt depth under the crystal-growth region is less than the critical depth. The thermal resistance of the quartz platform material is considerably greater than that of the molten silicon. This contributes further to stability by reducing the heat flux through the melt, thereby decreasing the thermal gradient that drives convection.

This work was done by Robert Richter of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 8 on the TSP Request Card.*
NPO-16597



The **Improved Crucible for Growing Silicon Crystals** would include a platform just below the growth interface.

Void-Free Lid for Food Packaging

A flexible cover eliminates air pockets in a sealed container.

Lyndon B. Johnson Space Center, Houston, Texas

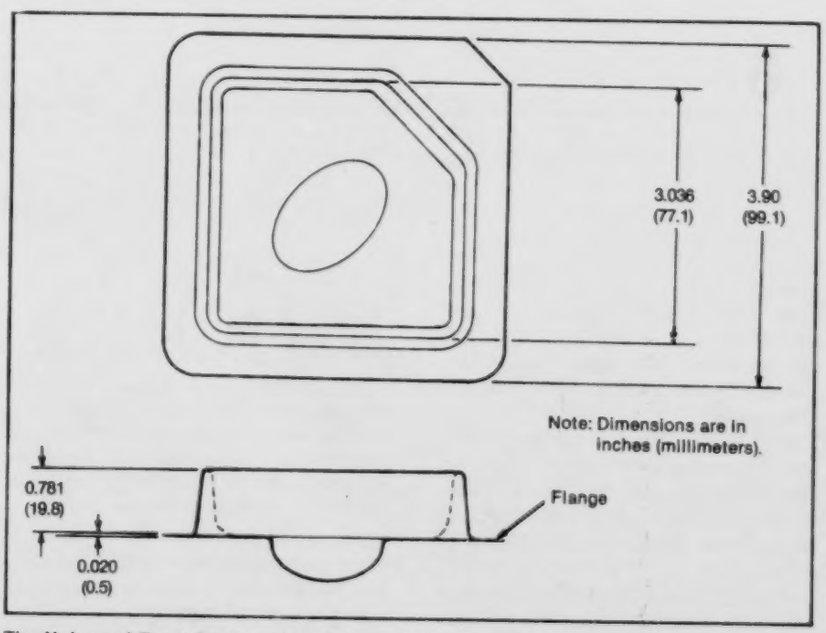
Containers holding varying, unpredictable levels of food are sealed at the precise fill level with the aid of a folding lid. The lid eliminates air or vacuum pockets above the food. It therefore keeps the food fresh, allows compact stacking of partially filled containers, and resists crushing.

The new lid was originally developed for packing dehydrated food for use in human consumption on the Space Shuttle missions. Other uses may include home canning and commercial food packaging.

The lid, made of folded, flexible plastic fits into a rigid plastic cup. The center of the lid is pushed into the cup to the top surface of the food. The lid unfolds as this is done and clings to the inside surface of the cup. The rim of the lid is then heat-sealed to the cup.

The new lid replaces an earlier model that, instead of having continuously variable depth, was available only in three fixed depths. That lid allowed voids when the container was filled to intermediate depths. It tended to crack and leak as a result and sometimes wrinkled, making it difficult to stack containers.

This work was done by Clyde D. Watson and William P. Farris of ESD Corp. for **Johnson Space Center.** *For further information, Circle 94 on the TSP Request Card.* *MSC-20661*



The **Universal Food-Package Lid** is formed from flexible plastic. Shown here partially folded, the lid is unfolded by depressing the center portion: The height of the flat portion of the lid above the flange is thereby reduced. The pressure of the food against the central oval depression pops it out, forming a dome that provides a finger grip for mixing the contents with water or opening the lid.

Metalizing Solar Cells by Selective Electroplating

Contact patterns are traced by laser scanning.

NASA's Jet Propulsion Laboratory, Pasadena, California

Conductor paths have been deposited on silicon solar-cell wafers by laser irradiation followed by electroplating. The laser-assisted metalization technique offers better resolution and lower contact resistance than does conventional metalization by screen printing. At the same time, it is less expensive than metalization with masks and photolithography.

In preliminary experiments, a layer of Ti 1,500 Å thick was first evaporated onto a silicon wafer. This was followed by a layer of Pd 500 Å thick. (These layers were deposited to promote the adhesion of the metal to be deposited and to reduce diffusion between the metalization and the silicon substrate.) Twelve comb-shaped metalization patterns for solar cells were then written on the wafer by an argon laser.

The laser beam was focused to a diameter of 50 μm and was moved in a raster pattern over the wafer by scanning mirrors. Each comb consisted of five 9-mm-long horizontal teeth, 2 mm apart. The combs were connected by a 9-mm-long vertical line on which a contact pad measuring 1 by 2 mm was centered. The lines were written in a single scan with a laser power of 7.7 W and a beam spot of 20 cm/s. The contact pad was written at the same power with a scan speed of 0.2 cm/s and a scan overlap of 60 percent.

No marks corresponding to the laser scan were visible on the wafer surface, even under a high-power microscope. However, when the wafer was immersed in a silver cyanide electroplating bath with 10 mA of plating current, the hitherto-invisible contact pads plated instantly. The lines, which were written at higher speed, took longer to plate and become visible.

A subsequent experiment was performed with a uniform scanning speed of 0.2 cm/s for both pads and lines. After plating for 3 h, the Pd and Ti over the rest of the wafer were etched off. Since the etchant oxidized the surface of the silver contact pattern, the oxide was removed in the plating solution, and the contact pattern was plated for an additional 30 min to restore the thickness. The final plated contact thickness was 25 μm.

Laser-written patterns on bare silicon and on silicon coated only with titanium were also plated selectively. It therefore seems likely that a laser-induced modification of the surface—laser-induced abrasion, for example—is responsible for the selectivity. On bare silicon, the plated silver did not adhere well. On the titanium-coated surface, however, the silver adhered well. This is an important finding because it means that it may be possible to reduce costs by doing away with the palladium layer.

This work was done by Subhandra Dutta and Patricia A. Palaschak of Westinghouse Electric Corp. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 90 on the TSP Request Card.* *NPO-16600*

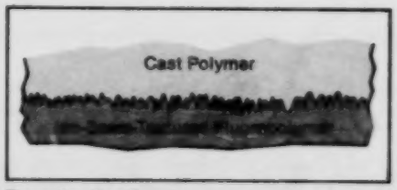
Transfer Casting From Ion-Beam-Textured Surfaces

Textured surfaces are created on metals, ceramics, and polymers.

Lewis Research Center, Cleveland, Ohio

A technique has been developed to generate precise, controllable, surface microstructures on metals, ceramics, and polymers. An electron-bombardment ion thrustor is used as a neutralized-ion-beam source. The beam of directed, energetic ions can alter the surface chemistry and/or morphology of many materials. By adjusting the ion energy and ion-beam current density impinging upon the target, precise surface modifications can be obtained without risk of target-material melting or bulk decomposition.

A given ion-source operating condition results in a certain repeatable surface morphology for each material. Metals and ceramics generally can be sputtered at high ion-beam energies (1,000 to 2,000 eV), high ion-current densities (1 to 2 mA/cm^2), and high surface temperatures (~500 °C). Metals sometimes require the use of a sputter-resistant material (seed), which is simultaneously sputter-deposited onto the metal surface during sputtering, to obtain a desired surface microstructure. The average separation between surface microstructures may range from less than 1 μm to 10 μm or more, and the average height of these features may range from less than 1 μm to 10 μm or more. Polymers generally require low ion-beam energies (~500 eV), low ion-current densities (~0.1 mA/cm^2), and low surface temperatures (<200 °C) to obtain a desired surface microstructure without thermal damage. The average surface-feature separation for polymers ranges from less than 1 μm to 10 μm or more, and the average height ranges from less than 1 μm to 100 μm or more.



Transfer Casting is used to reproduce a surface with microscopic roughness: A polymer duplicate is cast on a fluoropolymer master, the surface of which has been given a texture by ion-beam sputtering.

To obtain a larger surface roughness on any material, a screen mesh may be superimposed on the target material during sputtering. The screen will prevent the sputtering of material directly beneath it, resulting in a surface with an array of holes of known dimensions. By varying the size of the screen apertures (present range is 14 μm to 200 μm.) and the ion-sputtering duration, different pit widths and depths can be obtained. The screen thickness limits the maximum pit depth.

The following list enumerates the limitations of ion-sputtered surface modifications:

1. Many hydrocarbon polymers do not develop a natural texture by beam sputtering.
2. Many polymers have very low sputtering yields; i.e., long ion-machining times to get a pit array.
3. A surface with pillars is very difficult to obtain.
4. Ion-beam sputtering alters the surface chemistry of most materials.

A method using a transfer-casting technique has been devised to overcome these shortcomings. As an example, ion-beam sputter texturing is used to develop a microscopically rough surface on a fluorocarbon polymer, such as polytetrafluoroethylene or fluoroethylenepropylene. These fluoropolymers easily develop surface texture by ion-beam sputtering.

The polymer to be surface-roughened is then cast over the textured fluoropolymer as shown in the figure. Other inorganic, organic, nonmetallic, and metallic ion-beam-textured substrates can be used for the negative casting by sputtering a thin fluoropolymer coating over the texture to allow release of the cast polymer. A wide variety of polymers can be cast over the textured fluoropolymers, such as silicone rubbers, polyurethanes, polyolefins, and other low-elastic-modulus polymers.

There are many applications for these unique surface modifications. Natural-textured and seed-textured metals have high solar-absorptance values (0.97). The bonding strength of adhesive-bonded, natural-textured PTFE approaches that of the bulk material. In the biomedical area, ion-machined and natural-textured PTFE and polyoxymethylene enhance cellular attachment to soft tissue. Ion-machined metals increase the hard-tissue (bone) attachment to implants by as much as 10 times the attachment to smooth-surface implants. The fibrous capsule thickness for natural-textured PTFE and polyoxymethylene implanted in soft tissue is less than the capsule thickness for smooth-surface implants.

This work was done by Bruce A. Banks, Albert J. Weigand, and James S. Sovey of **Lewis Research Center.** *Further information may be found in NASA TM-81721 [N81-21129/NSP], "Ion Beam Applications Research — 1981 Survey of Lewis Research Center Programs." [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

This invention has been patented by NASA [U.S. Patent No. 4,329,385]. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center, [see page 29]. Refer to LEW-13120.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Making Latex Microspheres in Space

Equipment yields larger, more uniform particles.

Two NASA reports describe the first commercial product to be manufactured in space. The product is monodisperse latex, a suspension of spherical particles of essentially the same diameter. Carried aboard the Space Shuttle on its orbital missions, a monodisperse latex reactor (MLR) produces spheres of much larger size than is possible on Earth. Microspheres 30 μm in diameter have been produced, whereas 5μm are the limit for Earthbound reactors. Microspheres as large as 100 μm are scheduled for production in the MLR.

The MLR-manufactured particles are highly uniform. The standard deviation in their diameter is less than 1.4 μm.

Latexes made on Earth lose their monodisperse character when the particle diameter gets much above 5 μm because the suspension starts to separate. The reacting compounds float to the surface or drop to the bottom of the reactor under the influence of gravity, and particles of widely varying size result. Stirring the mixture does not help to maintain the suspension; it only coagulates the particles into an amorphous mass. In the nearly zero gravity of a Space Shuttle orbit, however, flotation and sedimentation do not occur, and particles can grow to larger sizes without losing their uniformity.

The monodisperse latexes from space are offered for sale by the National Bureau of Standards to research workers around the world as standards for microsphere size. They can be used for calibrating optical and electron microscopes, laser light-scattering apparatus, and many other kinds of laboratory equipment. They may also find use as probes for determining membrane pore size and as carriers for pharmaceuticals, tracer chemicals, or biological species in which particle volume and surface area must be accurately controlled.

The MLR consists of a boxlike support-electronics package and a drumlike experimental-apparatus container. The container holds four independent reactors, each of which produces a batch of 100 ml of latex during a flight by seeded-emulsion polymerization. The reactors are loaded before a launch with latex ingredients chosen to produce the requisite particle size. Once the Space Shuttle is in orbit, the crew turns on the reactors, and the reactions proceed automatically.

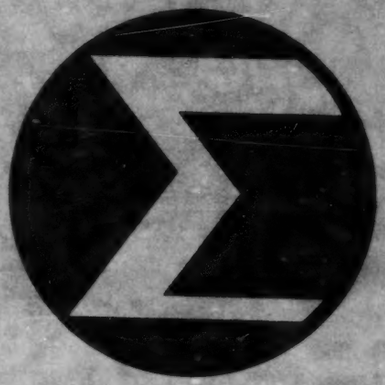
Each reactor is a small hollow steel cylinder with a stirrer at one end and a piston at the other. The piston moves to accommodate expansion and contraction of the contents as the reaction progresses. Heating tape wrapped around a reactor supplies heat in accordance with a temperature/time profile programed in a microprocessor controller. After 20 h, polymerization is complete, and the reactors turn themselves off. A linear variable-differential transformer on the piston and thermocouples on the heating tape send volume and temperature data to a recorder in the support-electronics package.

The reaction converts liquid styrene monomer into hard, colorless polystyrene spheres. The initiator is azobisisobutyronitrile (AIBN). When heated to 70° C, AIBN decomposes into two radicals plus a molecule of nitrogen gas. The secondary carbon atom in the radicals is highly reactive and adds a styrene molecule to itself. This composite molecule adds another styrene molecule and so forth, building a long, linear chain of styrene units. Growth stops when the chain meets another growing chain or a radical.

Billions of these long chains of polystyrene are formed inside latex seed particles introduced into the initiator. The particles thus swell to the required larger size.

This work was done by Dale M. Kornfeld of **Marshall Space Flight Center** *and J. W. Vanderhoff, M. S. El-Aasser, F. J. Micale, E. D. Sudol, C. M. Tseng, and A. Silwanowicz of Lehigh University. To obtain copies of the report "Production of Large-Particle-Size Monodisperse Latexes," and "Monodisperse Latex Reactors," Circle 63 on the TSP Request Card. MFS-27085*

Mathematics & Information Services



Hardware, Techniques, and Processes

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Simplified Decoding of Convolutional Codes

Some complicated intermediate steps are shortened or eliminated.

NASA's Jet Propulsion Laboratory, Pasadena, California

The decoding of convolutional error-correcting digital codes is simplified by a new error-trellis syndrome technique. Existing decoding algorithms combined with new mathematical identities reduce the number of combinations of errors that have to be considered and enable the computation of the correction vector directly from the data and check bits as received.

In decoding a convolutional binary error-correcting code, the decoder must decide, on the basis of probabilities, whether the correct value of each digit received is zero or one. This decision is made according to an algorithm that operates on the sequence of a specified number of digits leading up to the present digit. Since the decision also had to be made and may yet have to be revised for each preceding digit in the sequence, the present assumed value can be represented as being connected to the previous values through a tree formed by the alternative decision paths.

Traditionally, the determination of the error pattern and the selection of the path through the decision tree have involved the intermediate step of computing a syndrome vector. The syndrome vector consists of all zeros if the assumed sequence satisfies the constraints of the code. If the syndrome vector is not zero, however, it does not provide the correction vector (the sequence of correction digits) directly. Starting with the syndrome, it is still necessary to engage in a complicated search for the error locations in the tree.

In the new technique, the syndrome vector is not computed. Instead, advantage is taken of newly-derived mathematical identities that simplify the decision tree, folding it back on itself into a form called the "error trellis." This trellis is a graph of all path solutions of the syndrome equations. Each path through the trellis corresponds to a specific set of decisions as to the received digits.

The path for which the error pattern includes the minimum number of corrections to the previously-assumed digit sequence is considered to be the maximum-likelihood path through the trellis. The correction vector corresponding to the maximum-likelihood path is applied to the previously assumed sequence, and the result is adopted as the newly assumed sequence of digits; that is, the corrected version of the noisy received message.

This work was done by Trieu-Kie Truong and Irving S. Reed of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 19 on the TSP Request Card.*
NPO-16514

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Report on Computer Programs for Robotic Vision

A collection of programs supports robotic research.

A report describes the computer-vision software library at NASA's Jet Propulsion Laboratory. The programs have evolved

during the past 10 years of research into robotics. The collection includes low- and high-level image-processing software that has been proved in applications ranging from factory automation to spacecraft tracking and grappling.

The programs fall into several overlapping categories. In the image utilities category are low-level routines that provide computer access to image data and some simple graphical capabilities for displaying the results of image processing. They include routines for the following:

- The input, output, and transfer of image data;
- Camera selection;
- Programing a pipeline image processor called the IMFEX (for IMage FEature EXtractor);
- Cursor control; and
- Interactive manipulation or generation of image data.

In the feature-extraction category are routines that extract image features based solely on the two-dimensional data array:

- Clustering algorithms extract regions from images based on properties (for example, brightness) of neighboring picture elements.
- Convolution algorithms transform the image array (for example, to enhance contrasts) by performing the same set of operations on the picture elements in a small window centered on each picture element in the image.
- A stereo correlation algorithm obtains the three-dimensional coordinates of points.

A camera-calibration program, based on a standard perspective transformation, is used to make three-dimensional measurements. The stereoscopic cameras of the robotic system are calibrated empirically by viewing several known three-dimensional points and recording the coordinates of the corresponding image points. These data are then used to solve for the camera-model parameters using least-squares techniques.

Coordinate-transformation routines perform a variety of functions involving the camera calibration. The two basic functions are the computation of the image coordinates of a given three-dimensional point and the computation of the ray containing all the three-dimensional points that have a given pair of image coordinates. Additional functions are defined by imposing various three-dimensional constraints.

The programs for the acquisition and tracking of objects provide the visual-data feedback needed for robotic control in changing scenes. These include programs for correlating successive images, label tracking for remote-manipulator control, object tracking with trajectory prediction, and finding a known moving object to begin tracking it. Some applications include grasping moving objects with a robot arm, obstacle avoidance by an autonomous vehicle, landmark navigation, and spacecraft-docking maneuvers. The basic requirement in such applications is fast processing to keep up with the standard television frame rates of 30 Hz (interlaced) or 60 Hz (noninterlaced). This, in turn, requires powerful image-processing hardware and powerful pipeline processors like the IMFEX.

This work was done by Robert T. Cunningham and Edwin P. Kan of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "JPL Robotics Laboratory Computer Vision Software Library," Circle 91 on the TSP Request Card.*
NPO-16565

WHAT CORROSIVE ENVIRONMENTS DO TO SOME METALS, AN IVADIZER® COATING STOPS COLD.

The Ivadizer aluminum coating process, developed to protect critical parts of military aircraft, will plate complex metal parts of any size with a dense, adherent, protective aluminum coating of uniform thickness. It does so economically and without pollution problems.

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For all the facts about the Ivadizer coating process, write to D.E. Muehlberger, McDonnell Aircraft Company, Dept. 357, P.O. Box 516, St. Louis, MO 63166. Or call (314) 232-5859.

MCDONNELL DOUGLAS

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Visual-Accommodation Trainer/Tester

Ophthalmic instrument tests and helps develop focusing ability.

Ames Research Center, Moffett Field, California

An ophthalmic instrument provides four functions: (1) it measures the visual near and far points; (2) it provides a focus stimulus in vision research; (3) it measures the visual-accommodation resting position; and (4) it can be used to train for volitional control of a person's focus response.

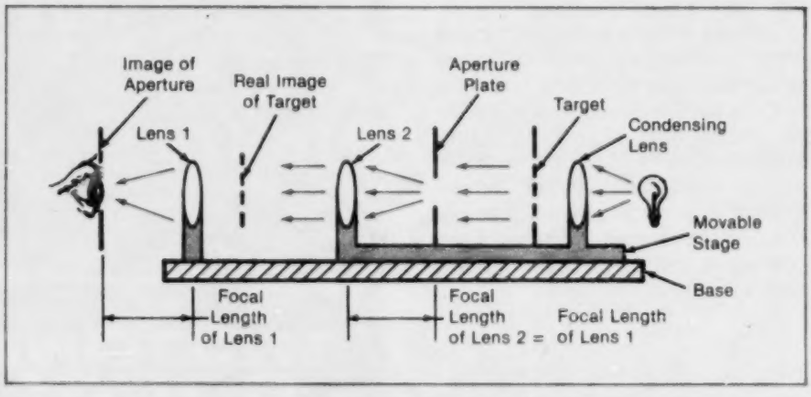
A pair of lenses, an aperture plate, a transparent target, and a target back-light source are mounted on a stage that can be moved along a baseplate (see figure). The aperture is at the focal plane of lens 2; therefore, the light rays from the aperture are collimated and impinge on lens 1 as a plane wave front. Lens 1 brings the image of the aperture to a focus at its left-hand focal plane. The subject's eye is positioned so that its entrance pupil is in this plane and coincident with the aperture image. This provides a nonintrusive artificial pupil of selectable size.

The target, a thin vertical luminous line on a dark background, is imaged a fixed distance to the left of lens 2. The image of the line is then the object for lens 1. Lens 1, with the eye at its second focal plane, forms a Badal subjective optometer. The dioptric power required by the eye is a linear function of the distance of the target image to the right of lens 1. Thus, to vary the power required at the eye, the movable stage is simply moved to the right and left. A dioptric scale is inscribed on the baseplate.

A mechanism is provided to quickly change aperture sizes. Three are selectable: (1) a wide-open, 8-mm circular hole, (2) a 0.3-mm circular hole, and (3) two 0.5-mm apertures placed side-by-side. The first is for using the system as a Badal optometer to measure and to stimulate the eye. The second is used to provide a large depth of focus (as in a pin-hole camera) and "open the accommodation loop." This provides a measurement of the resting position and allows the subject access to the control of his/her own focus. The third may be used in measurement as an alternate to the wide-open aperture. When the subject is not in the same focus as that of the trainer/tester, the image of the luminous line will be laterally split into two vertical, luminous lines by the two 0.5-mm apertures.

For the training application, apertures 2 and 3 are alternated. A defocused, split image is provided to the subject and he/she attempts to bring the images together without moving the stage. Aperture 2 can alternately be selected so the subject can practice, open loop, with brief returns to aperture 3 to check on progress in fusing the split images of the luminous line.

This work was done by Robert J. Randle, Jr., of **Ames Research Center.** *For further information, Circle 24 on the TSP Request Card.*
ARC-11426



The **Movable Stage** on a fixed base permits adjustment of the effective target position as perceived by the subject. Various apertures can be used to perform tests and training procedures.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Spring Small Grains Area Estimation

SSG3 automatically estimates the acreage of spring small grains from Landsat data.

A report describes the development and testing of a computerized technique for using Landsat multispectral scanner (MSS) data to estimate the acreage of spring small grains (wheat, barley, and oats). The application of this technique to the analysis of four years of data from the United States and Canada yielded estimates of accuracy comparable to those obtained through procedures that rely on trained analysts. An analysis of errors showed that even higher accuracy is conceivable if the sample segments are assigned proper growing degree-day models so that the data acquisitions can be correctly designated.

The Landsat MSS data-analysis techniques of interest were developed during the Large Area Crop Inventory Experiment (LACIE), carried out during 1974-77. These techniques provided monthly harvest estimates that were within 10 percent of the U.S. Department of Agriculture crop estimates, with a confidence level of 90 percent. These results depended heavily on well-trained analysts and on an intricate system of quality assurance and teamwork.

A major goal of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) program, initiated in 1980, was to ascertain whether the analysis procedure could be automated at a reduced cost, while the accuracy was maintained comparable to that reached in the analyst-intensive LACIE. Developed to meet this objective, the SSG3 is an expert system for the classification of remotely-sensed digital images.

The input data for this hierarchical procedure consists of from three to eight temporally spaced Landsat MSS acquisitions collected over a 5- by 6-nautical-mile (9.3- by 11.1-km) sample segment (177 lines, each containing 196 picture elements). The Kauth-Thomas transformation is applied to the four-channel MSS data before applying the procedural logic. The end products of this transformation are numerical values of greenness, brightness, yellowness, and nonesuch. The greenness value is stabilized by the subtraction of the greenness of bare soil from the greenness assigned to each picture element. The result is the green number, the temporal variation of which is used to determine the threshold values for the logic of the spring small grains used in the SSG3 procedure.

A systematic sample of 897 picture elements (every fifth line and sample) is selected from the segment for labeling. Samples are labeled by decision logic designed to exploit the temporal behavior of picture elements. The inferences that lead to a label for each picture element are based on characteristic temporal/spectral patterns that were determined by expert analysts to be significant for distinguishing between the spring small grains and other classes of vegetation present in the scene.

This work was done by Wesley F. Palmer and Robert J. Mohler of Lockheed Engineering & Management Services Co., Inc., for **Johnson Space Center.** *To obtain a copy of the report, "Test of an Automatic Procedure for Estimating Spring Small Grains Acreage from Landsat Data," Circle 43 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20973.

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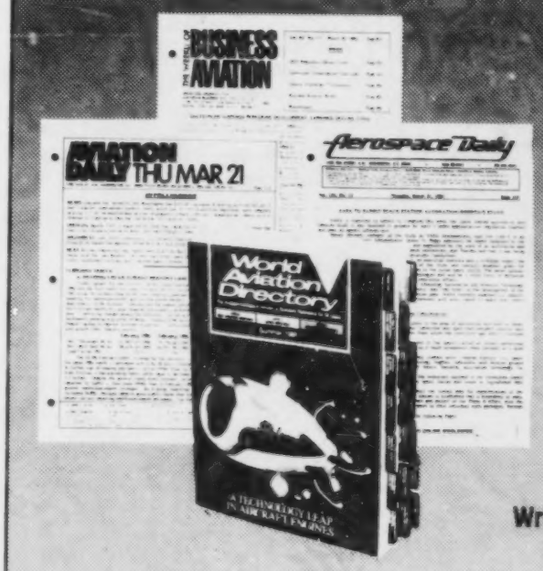

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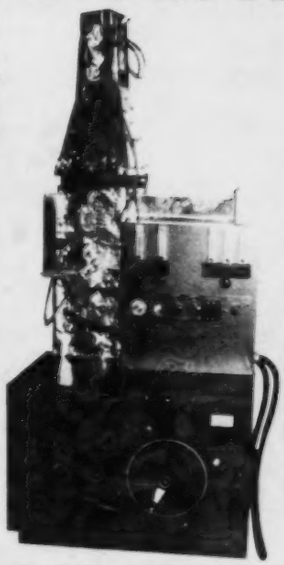

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The EcoSphere concept was originally developed by Joe N. Hanson, a scientist at Jet Propulsion Laboratory, as part of a NASA program researching bioregenerative systems capable of sustaining life in the space environment. After investigating the dynamics of microbial ecosystems, Hanson determined that such systems, sealed in one-liter flasks and exposed to light for extended periods, could survive for more than 15 years, a period comparable to that of the same ecosystem in a natural environment.

Eventually, Hanson was able to extend the range of the system to include crustacea and macroalgae. He added tiny shrimp and clusters of algae to his microbial soup, enclosing the entire system in a glass flask.

Loren Acker, president of Engineering and Research Associates, Inc. of Tucson, Arizona, saw one of the prototype flasks during a business visit with a NASA official. He obtained a license for the technology and began producing the EcoSphere in 1983. To date, nearly 4000 EcoSpheres have been produced as a sideline by the company, which also manufactures medical instruments.

In essence, the EcoSphere is a self-sustaining aquarium. Its only outside need is a source of light. The algae in the EcoSphere produce oxygen for the six shrimp, who feed on the algae and bacteria. The shrimp, in turn, excrete organic wastes that sustain the bacteria. Finally, the bacteria provide the carbon dioxide and inorganic chemicals that, when combined with light, sustain the algae.

Engineering and Research Associates has isolated a particularly light-tolerant algae for use in its EcoSpheres. Previously, they gathered part of the algae from the wild. "With that," says Acker, "we got all kinds of microscopic creepy crawlers that we couldn't control, so we isolated a specific strain and we grow it in a semi-sterile container.

"What we've basically added beyond the NASA technology," Acker says, "is what we call a synthetic system, that is the ingredients are quite highly predictable and, if you will, recipated." Recipe in hand, scientists and technicians have succeeded in synthesizing a naturally self-sustaining system in an artificial environment.

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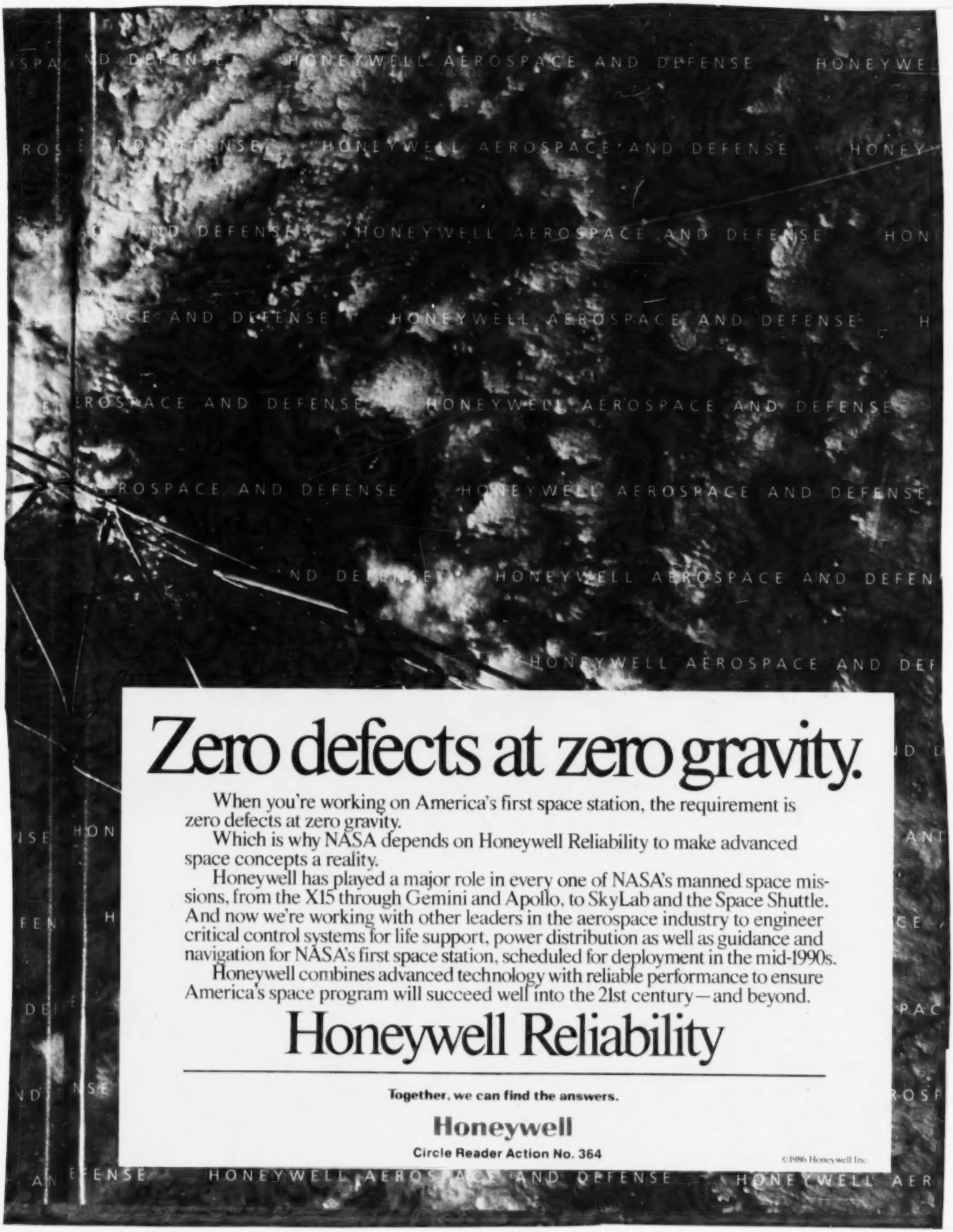

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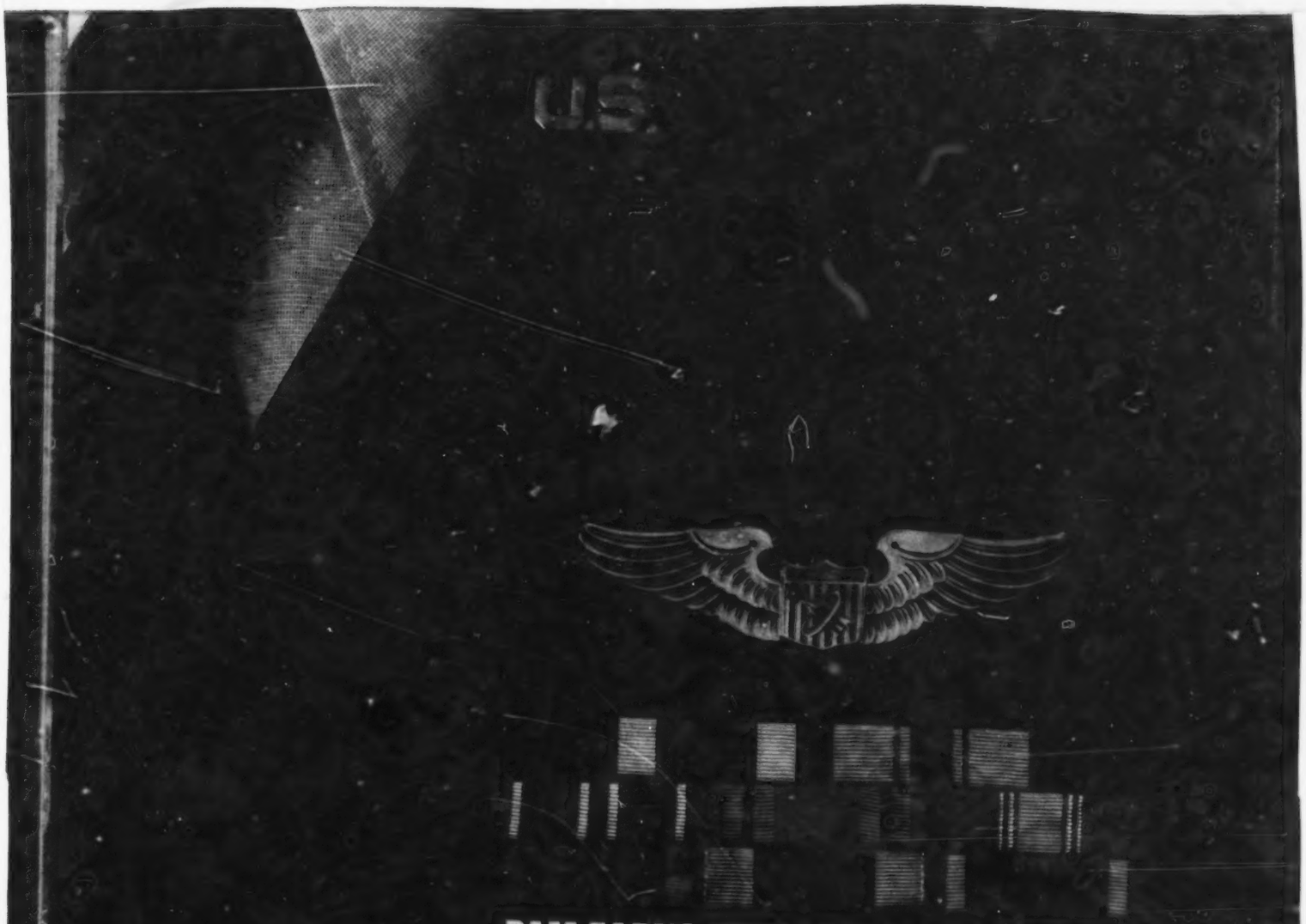

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National Aeronautics and Space Administration

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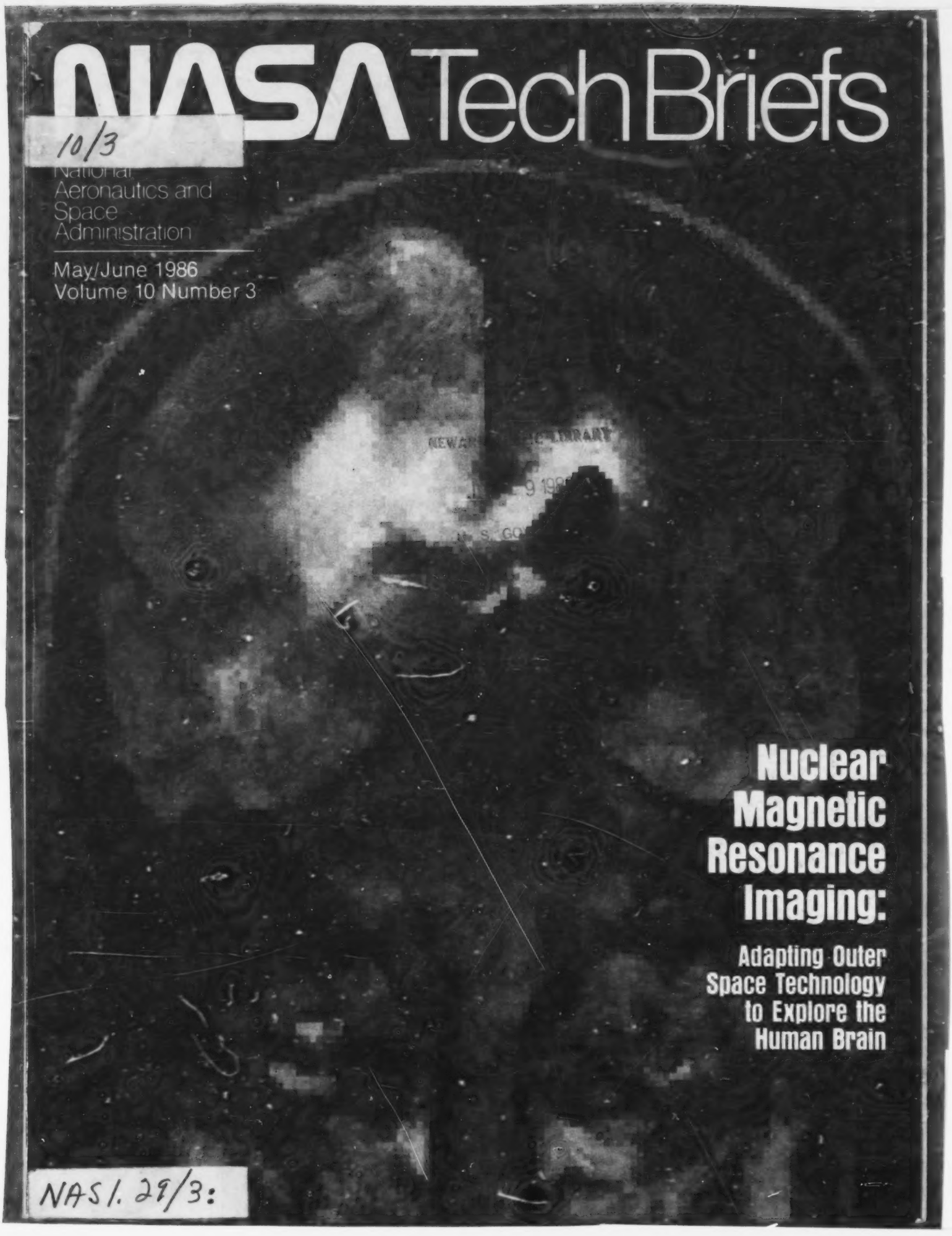
Volume 10 Number 3



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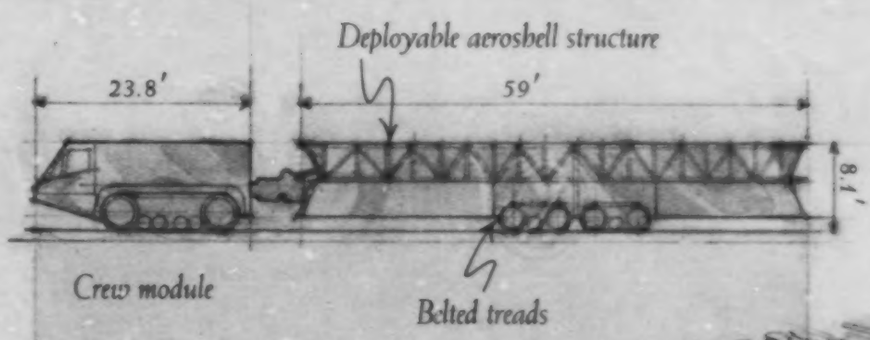

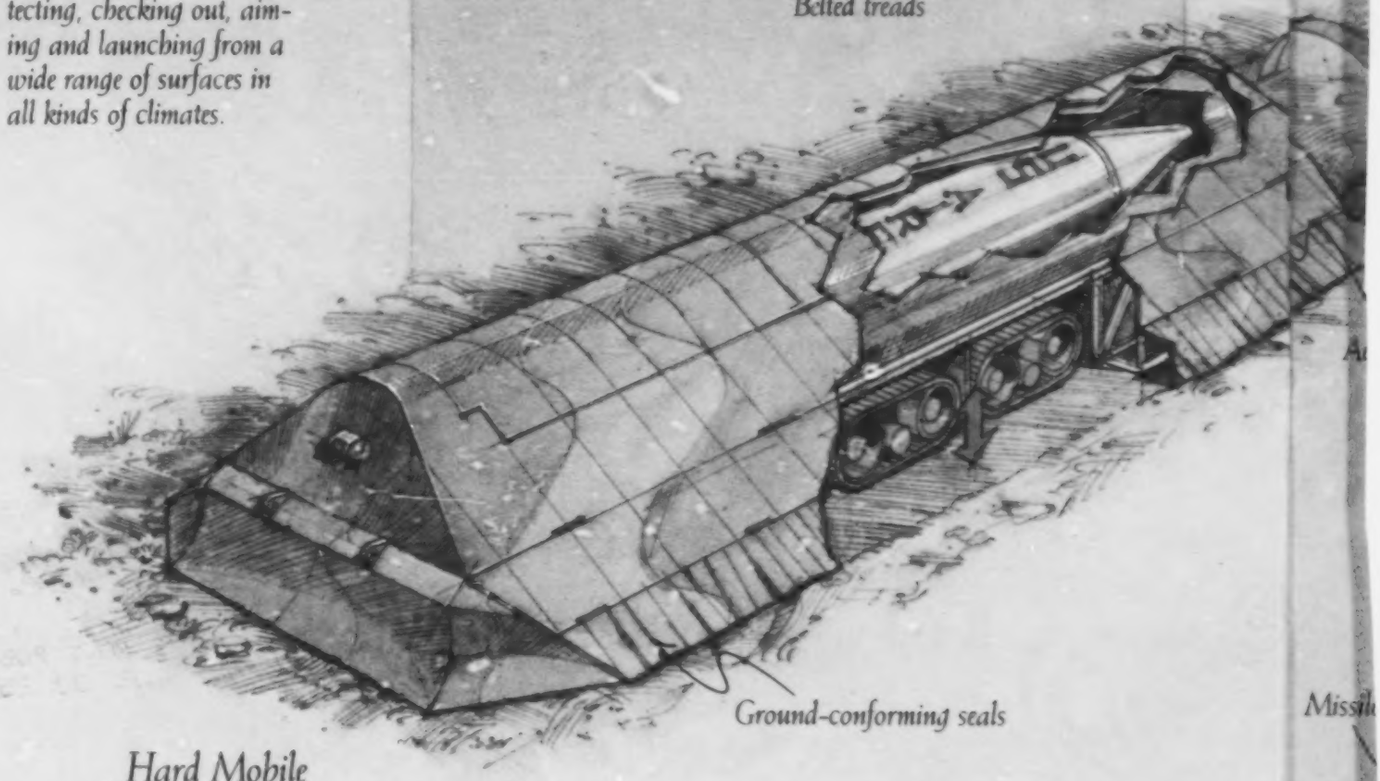

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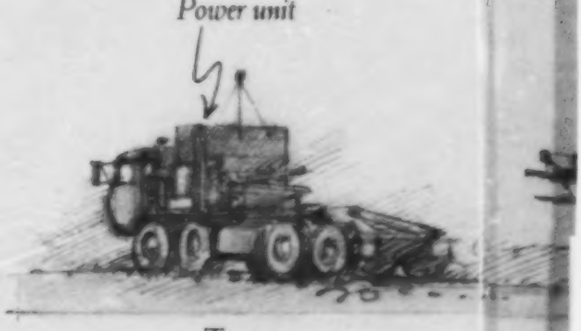

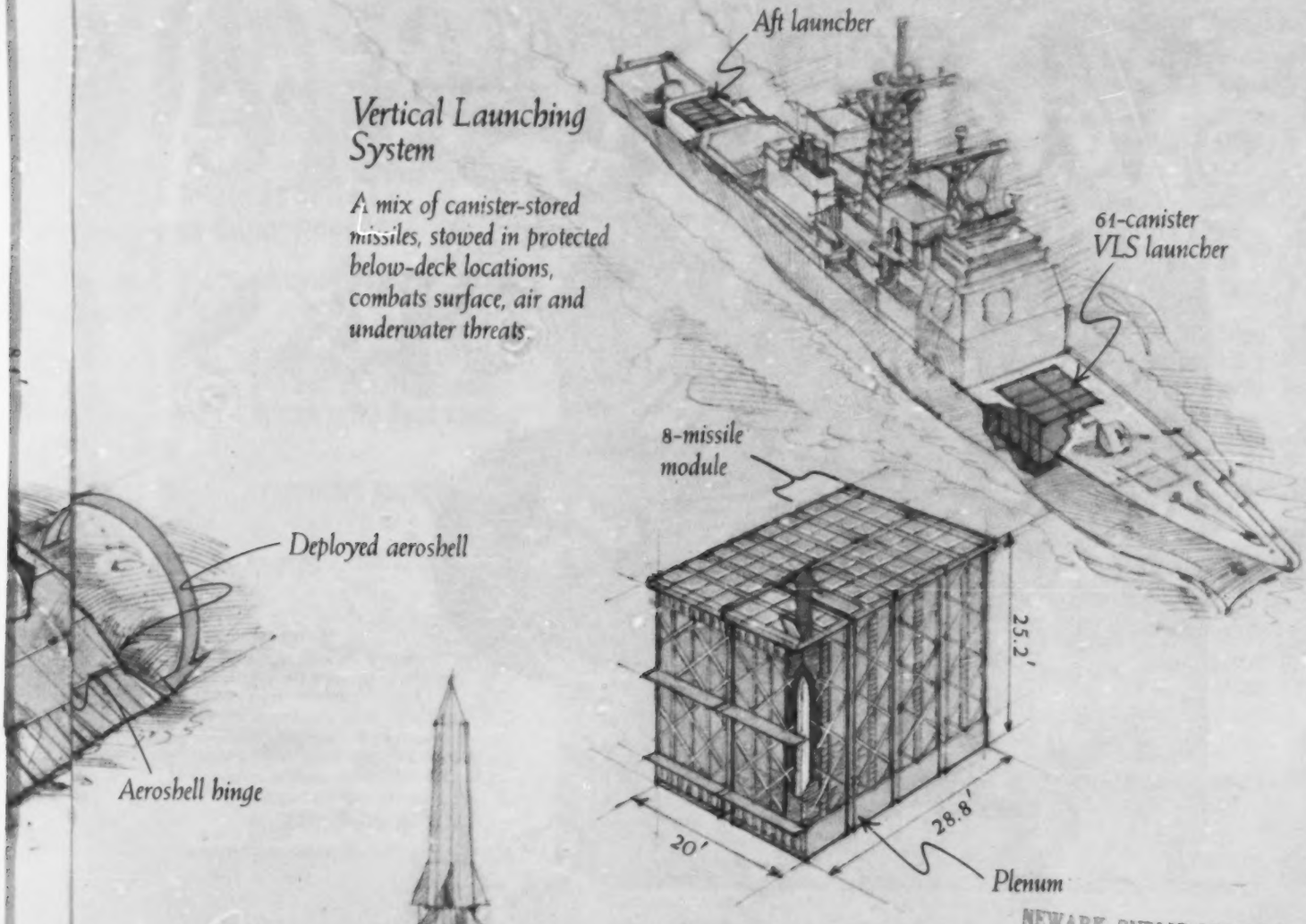

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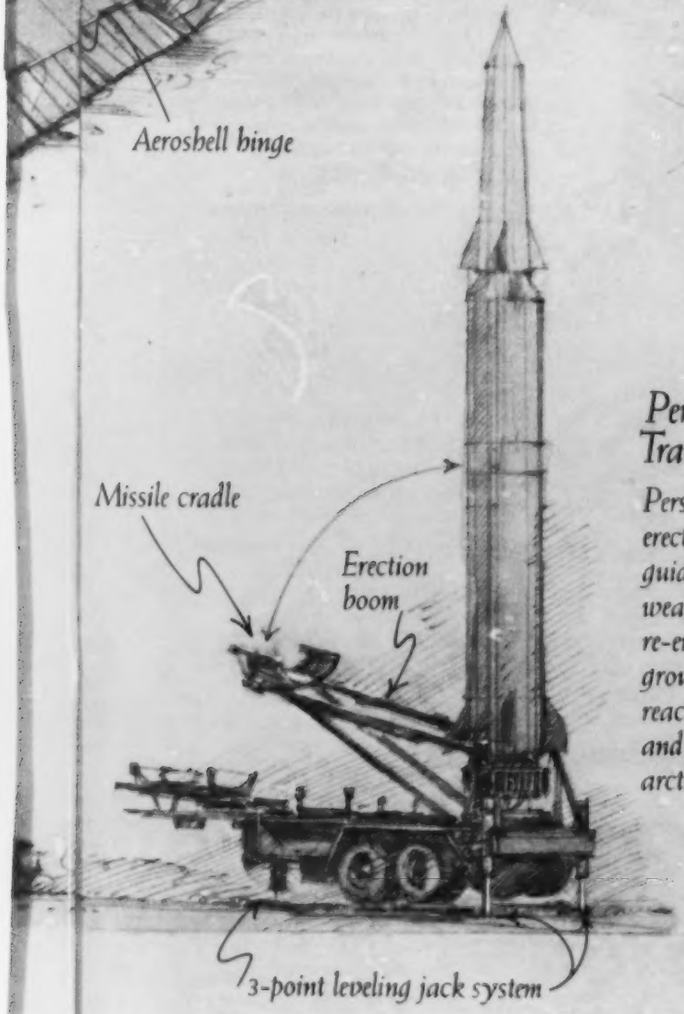

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National Aeronautics and Space Administration

MAY/JUNE 1986
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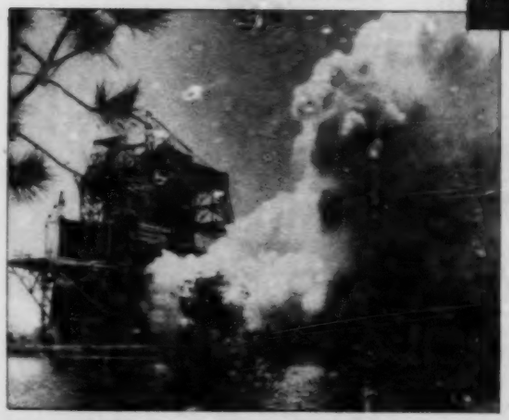
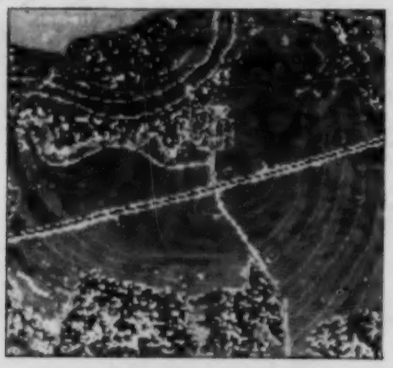
Remote sensing technology is being applied in disciplines as diverse as geology and pathology. The medical application is currently being advanced by an applications engineering project linking radiologists from Washington University Medical Center, St. Louis, Missouri, and NASA scientists at NSTL . . . page 165.



NASA's National Space Technology Laboratories, near Bay St. Louis, Mississippi, is the test site for the space shuttle's main engines. In addition to NASA, 17 other federal agencies are in residence at NSTL . . . page 12.



This computer-generated image served as a point of departure for archeologists studying Poverty Point, LA . . . page 12.

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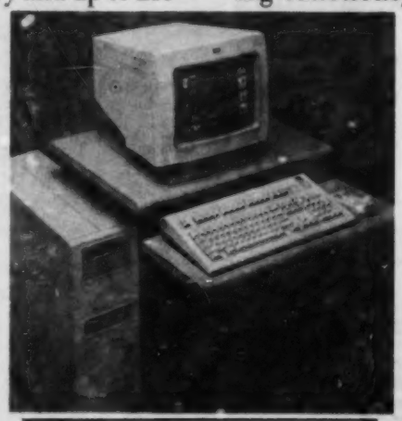

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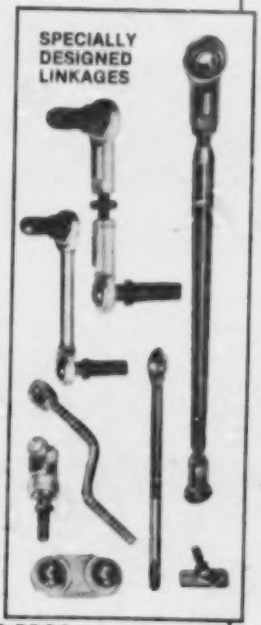

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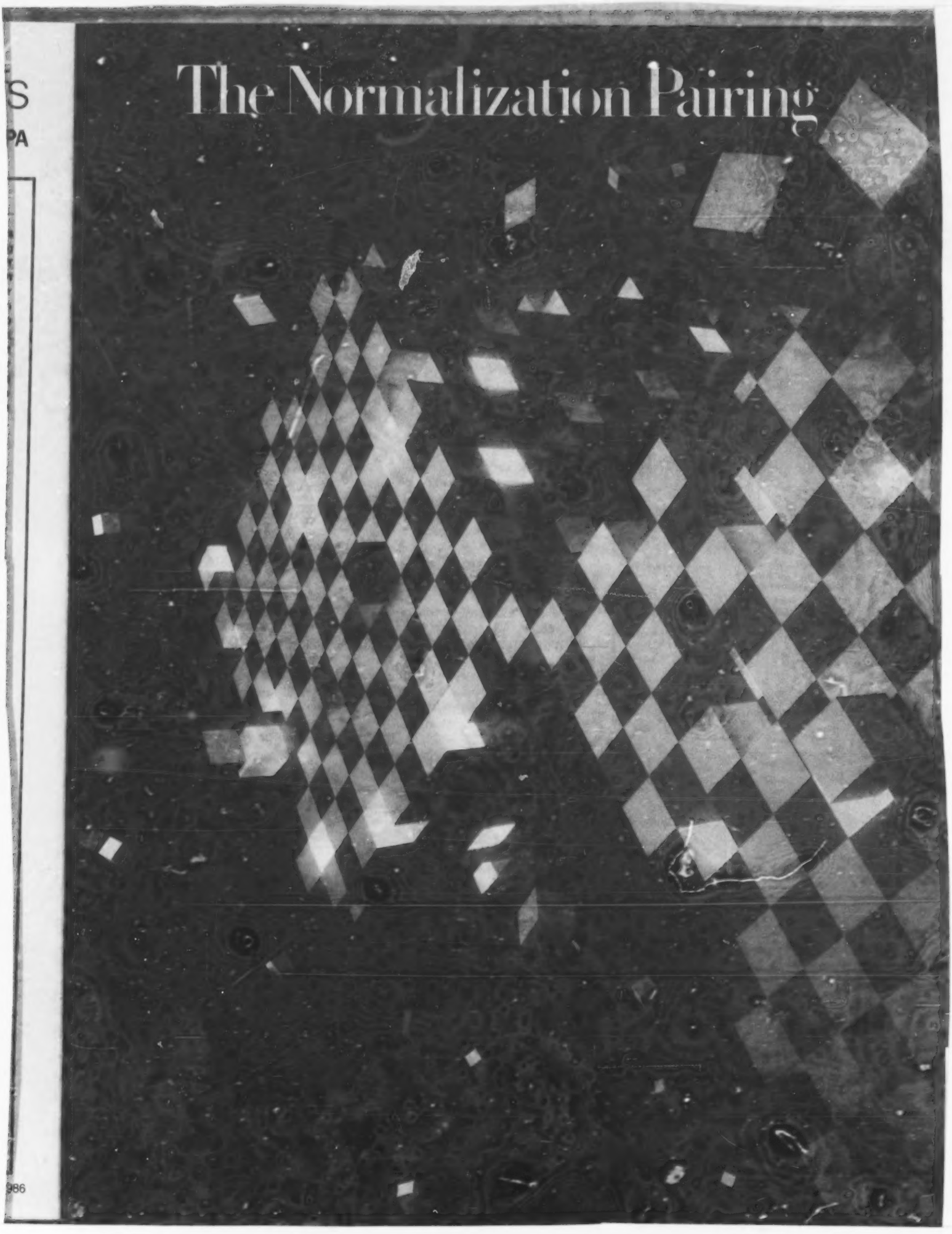

The Normalization Pairing

The Normalization Pairing

A scientist at the General Motors Research Laboratories has developed a new method for accurately determining the effectiveness of safety belts in preventing traffic fatalities. The approach may be used to answer a wide variety of questions using data bases that lack conventional measures of exposure.

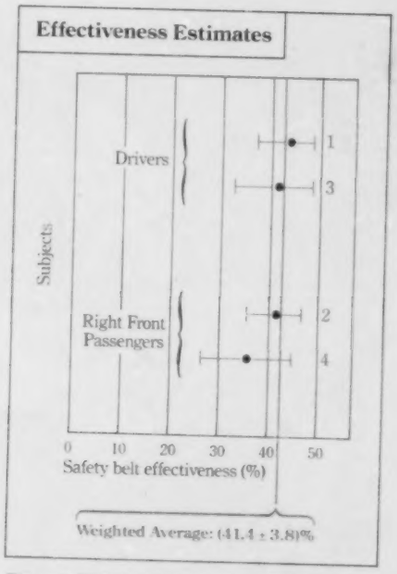


Figure 1: Weighted estimates of safety-belt effectiveness by subject, with standard error. Estimate 1 pairs subjects with right-front passengers; 2 pairs subjects with drivers; 3 and 4 pair subjects with occupants of all other seating positions.

THERE IS A serious problem that researchers often encounter when trying to analyze large collections of information. It is the problem of measuring exposure. Though a collection of data may contain a large number of cases, and though the facts in each case may be highly detailed, there may be no way of comparing events selected for inclusion in the collection against the normal occurrence of similar events in the world at large.

One such data base is the Fatal Accident Reporting System (FARS) maintained by the U.S. Department of Transportation's National Highway Traffic Safety Administration. FARS details all fatal accidents in the U.S. since January 1, 1975—more than 300,000 crashes. However, it lacks an explicit measure of exposure.

FARS contains, for example, the number of fatalities classified by safety belt use. But fatalities among users depend on two considerations: first, the effectiveness of safety belts; and second, the crash involvement differences between users and nonusers—that is, the exposure of belt users to crash involvement. If crash involvement were independent of belt use, it would be a simple matter to calculate the effectiveness of safety belts in preventing fatalities. However, belted drivers have fewer crashes, and the crashes they do have tend to be of lower average severity than those of unbelted drivers.

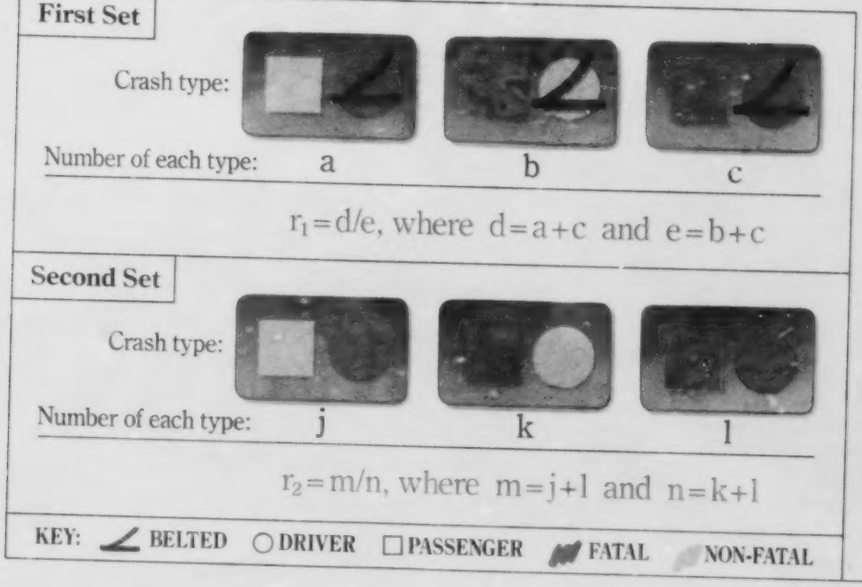
Now a scientist at the General Motors Research Laboratories has developed an approach to drawing inferences from FARS using only the information contained in the file. Dr. Leonard Evans has designed a method for comparing the effects of isolated characteristics by using two sets of crashes. In each set, a *subject* occupant is paired with an *other* occupant. In the first set, the subject exhibits the characteristic to be studied; in the second, the subject does not. The *other* occupant is chosen to have similar characteristics in both sets of crashes (e.g. always unbelted), and thereby acts as a measure of exposure.

To illustrate the workings of the method of double-pair comparison, Dr. Evans first applied it to a study of the effects of safety belt use on fatality risk. He could define the effectiveness of safety belts in terms of the ratio:

$$R_{true} = \frac{N_b}{N_u} = \frac{N' \int q_{D,b}(s) f_u(s) ds}{N' \int q_{D,u}(s) f_u(s) ds}$$

where N′ is the number of crashes per year by unbelted drivers, s is crash severity, $f_u(s)$ is the probability that a crash involving an unbelted driver has a severity s, $q_{D,u}(s)$ is the probability that an unbelted driver will become a fatality in a crash of severity s, and $q_{D,b}(s)$ is the probability that a belted driver will become a fatality in a crash of severity s. R_{true} is a ratio of new to

Figure 2: Schematic representation of a sample double-pair comparison.


First Set
Crash type:
Number of each type: a b c
$r_1 = d/e$, where $d = a + c$ and $e = b + c$
Second Set
Crash type:
Number of each type: j k l
$r_2 = m/n$, where $m = j + l$ and $n = k + l$
KEY: BELTED DRIVER PASSENGER FATAL NON-FATAL

old fatalities—assuming a formerly unbelted population became a belted population, with nothing else changing. But while N_u, the number of unbelted driver fatalities, can be determined from the FARS data, N_b, the number of these who would still have been fatalities had they been wearing safety belts, clearly is not coded in the data base.

Dr. Evans applied the double-pair comparison method to determine a quantity, R, that would, under plausible assumptions, accurately estimate R_{true}. Figure 2 shows the pattern of the first application. In it, one set of crashes paired belted drivers and accompanying unbelted front-seat passengers, generating a ratio, r_1, of belted driver fatalities per unbelted passenger fatality. The second set paired unbelted drivers with unbelted front-seat passengers, leading to a ratio, r_2, of unbelted driver fatalities per unbelted passenger fatality. This yields a value of $R = r_1/r_2$ as a measure of safety-belt effectiveness.

IN ADDITION to calculating R for driver *subjects* using front-seat passenger *others*, effectiveness was also calculated for right-front passenger *subjects* using driver *others*. Additional calculations were made pairing driver or right-front passenger *subjects* with passengers in any other seating position. Figure 1 reflects the synthesis of these estimates. Estimates 1 and 2 represent *subject* and *other* occupants disaggregated into three age categories and averaged. Estimates 3 and 4 represent pairings of *subjects* with occupants in other seating positions and averaged.

In all, Dr. Evans calculated 46 estimates of R. The weighted average of these gives a safety-belt effectiveness of (41.4 ± 3.8)%. This should be an accurate estimate whenever the distribution of severities is the same for both sets of crashes in each double-pair comparison.

Moreover, a formal analysis showed r_1/r_2 to be an accurate estimate of R_{true} under much less stringent restrictions. Even when the distributions of crash severity differ for belted and unbelted drivers, Dr. Evans concluded that the simple ratio $R = r_1/r_2 = nd/me$ is indeed an accurate estimate of safety-belt effectiveness.

Dr. Evans' confidence in the method rests on some key assumptions. But, as he points out: "One of the beauties of the method is its ability to remove the biasing effects of confounding interactions that may undermine those assumptions. It is necessary only to disaggregate occupants into different categories of the suspect variable.

"Because of bias elimination, and the ability to create a measure of exposure, the method of double-pair comparison lends itself to a broad range of investigations. We can estimate, for example, fatality risk as a function of helmet use by motorcyclists, or safety-belt effectiveness in different accident types. More broadly, we can estimate fatality risk as a function of age, sex, or alcohol use. We may even have revealed a trend in trauma response, in general, as a function of sex and age."

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MARK OF EXCELLENCE

THE MAN BEHIND THE WORK

Dr. Leonard Evans is a Senior Staff Research Scientist in the Operating Systems Research Department at the General Motors Research Laboratories.

He received his undergraduate degree in physics from The Queen's University of Belfast, and holds a D. Phil. in the same discipline from Oxford University. He was a Post-Doctorate Fellow at the National Research Council of Canada in Ottawa.

Since joining GM in 1967, Dr. Evans has published research on such diverse topics as atomic physics and trauma analyses. His current area of concentration is traffic safety research.

He is a member of the Human Factors Society and is a Past President of the Society's Southeastern Michigan Chapter. In 1985, Dr. Evans received the Society's A. R. Lauer Award "for outstanding contributions to the human factors aspects of highway safety."

Editorial Notebook

Getting the Word Out

Every so often I get the feeling that this column resembles the form letters I sometimes receive at Christmas from well-intentioned friends. I like hearing from them, but I'd like it better if I got some personal communication.

So when I tell all of you that those of us associated with *Tech Briefs* like hearing from you via the feedback cards, I feel I ought to be sending more personal responses. Considering the amount of feedback we receive, this just isn't possible. Still, I think it's important for me to note that I read every single card.

Closing the loop on my analogy, thank you all for your responses, and please keep them coming. We appreciate your ideas for new approaches, and the positive and negative criticism. We're gratified that the positive-to-negative ratio is 99-to-1.

Some of the feedback cards we receive note the use of NASA-derived technology. We like to follow up on these for possible inclusion in *Spinoff*, an annual NASA publication designed to tell the public about products and services that have come about because of, or been enhanced by, NASA's ongoing technology transfer efforts. Sometimes we find that people are a little nervous about having used the NASA technology they've read about in *Tech Briefs*. This shouldn't be. The reason we publish *Tech Briefs* is to get the technology used. If a given invention or process needs a license, it says so in the brief. If it doesn't, use it.

The benefits of being published in *Spinoff* sometimes go beyond the realm of education into the cold, crass world of cash. What brings this to mind is the EcoSphere,® a technology transfer first published in *Spinoff* and republished in "Mission Accomplished" in the last issue of *Tech Briefs*. As we reported, Engineering and Research Associates of Tucson, Ariz., has sold some 4,000 EcoSpheres as a sideline, and last issue's republication brought about a rash of new inquiries.

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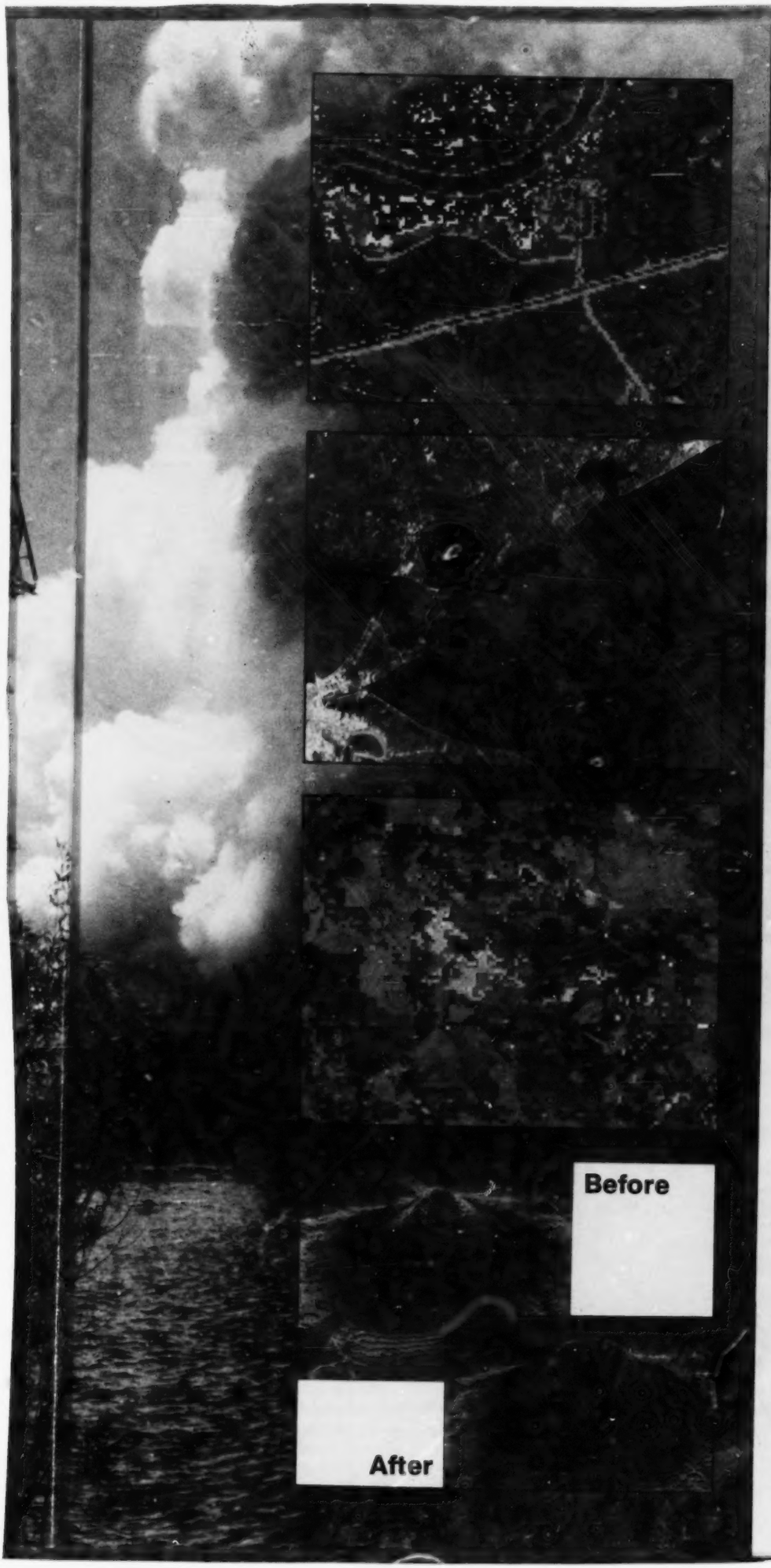

National Space Technology Laboratories:

High-Tech Mecca In The Deep South

From the Civil War to the civil rights era, Mississippi has played an important role in shaping the political history of this nation. On the cultural horizon, many a bright star has risen out of Mississippi, among them the singers Elvis Presley and Leontyne Price, and the award-winning writers William Faulkner, Tennessee Williams and Eudora Welty. Still Mississippi has a reputation as a rural, agrarian, poor and—in a word—backward kind of place. Few of us would think to look there when trolling for high technology.

To find high technology anywhere, you have to know where to look. In Mississippi, the place to start is along the Gulf Coast, in southeastern Hancock County near Bay St. Louis, at NASA's National Space Technology Laboratories. ►

Against the backdrop of a shuttle main engine test firing are four images generated from remotely-sensed data at NSTL's Earth Resources Laboratory. Top to bottom they are: A thematic map of Poverty Point, Louisiana, showing a subterranean system of archeological interest. The 400-acre site may date back to 1800 B.C., making it one of the oldest sites in the Americas; A satellite view of the Mississippi Gulf Coast; A thematic map of Arrow Point, Manitoba, that delineates land cover categories for use in surveying waterfowl nesting habitats; Before- and after-eruption images of Mount St. Helens generated from digital terrain data.

In 1992, we set sail for a New World.

In 1492, a Genoese navigator and an intrepid crew crossed unknown waters in search of a west passage to India. In the process, they uncovered the vast continents of two continents. And they opened up a new base for exploration, progress and the hopes of mankind.

Harris Aerospace, as a member of the Rockwell, Grumman and Sperry team, is responsible for the Space Station's communications and tracking system. We are totally committed to this great endeavor, and we bring to the challenge the capabilities and experience necessary for success.

Harris has had 27 years of successful involvement with the kind of space communications and tracking required for the manned Space Station. Our space experience includes programs from Telstar to the Tracking and Data Relay Satellite as well as the manned programs of Apollo, Lunar Module, and Space Shuttle. We are also a leader in the architecture and design of large communication networks.

Now, Harris is ready for the Space Station. Over the next years and centuries, the scope of scientific, commercial and technological opportunities and breadth of results are sure to exceed our wildest expectations.

For in 1992, we, too, will be very much like Columbus: carrying the sum of our knowledge into the unknown. And, like him, we, too, shall return with the bountiful gifts of a New World.

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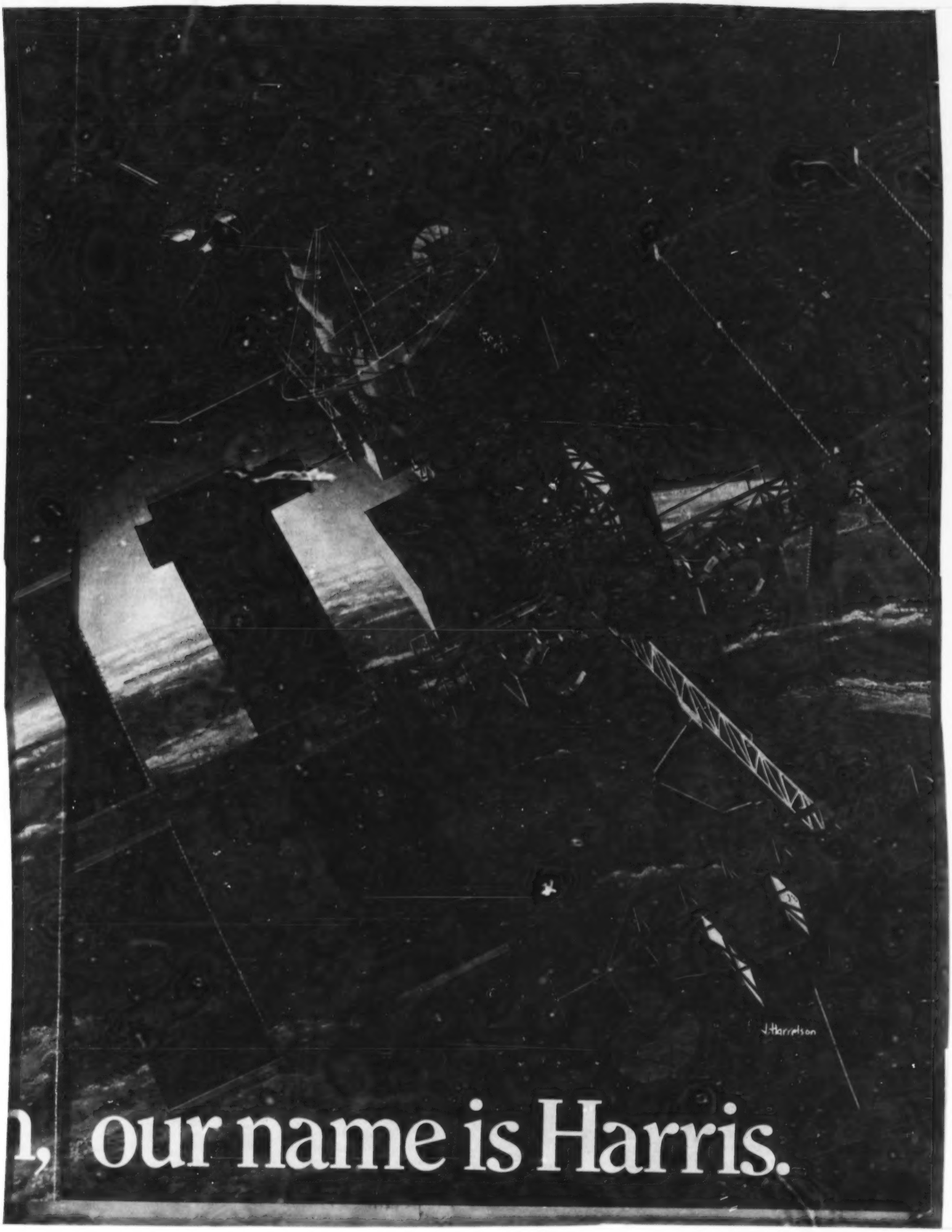

n, our name is Harris.

A single shuttle main engine undergoes test firing at NSTL. The engines are tested singly and in the three-engine cluster that, along with two solid rocket boosters, powers the shuttle during its 8½-minute flight to low-earth orbit.

NASA's presence in Mississippi dates back to the Apollo era, when the expanding agency acquired a new site for test firing the Saturn V rockets that would boost man to the moon. In the early 1960s, NASA purchased several thousand acres of land adjacent to Mississippi's East Pearl River and negotiated a perpetual easement on an additional 125,000 acres. The extra acreage would provide an acoustical buffer zone to ensure that the tremor-like vibrations and low-frequency roars that accompanied the test firing of the Saturn V would go relatively unnoticed. Even so, one test engineer who worked at the facility during this period recalled conferring with a NASA colleague in Mobile, Alabama, after a test-firing. The colleague was able to pinpoint the time and duration of the test, saying he'd felt the vibrations even though he was 100 miles away. Closer to the Mississippi site, the test engineer added, "You were more likely to feel that the shirt was being shaken right off your back."

While its remote setting was definitely a factor, the southern Mississippi site was also an appropriate choice because it falls within the boundaries of NASA's "space crescent," a geographic area stretching east from Houston to Cape Kennedy and north to Marshall Space Flight Center in Huntsville, Alabama. But finally, the Mississippi site was selected primarily for its proximity to water. Site development involved constructing nearly eight miles of canals to link the Mississippi Test Facility with the East Pearl River. The man-made canal system allowed the huge Saturn V rocket stages to be transported via barges from the Michoud Assembly Facility, near New Orleans, to the test facility. After testing, they were turned around—via the canals, the East Pearl and the Intracoastal Waterway—for launch at Cape Kennedy.

Other site development included the building of three mammoth concrete and steel test stands adjacent to the canals, plus associated test facilities, including a 64 million gallon reservoir, a power generation plant and a large gas pressure complex. Control centers, laboratories and administration and engineering offices were also constructed, along with roads to link the facility with the state's highway system.

When the Mississippi Test Facility became operational in 1966, it had developed into a city unto itself, complete with post office, fire department and hospital. The southern Mississippi metamorphosis that began with the transition of rural, wet, snake-infested farmland into a space-age technological outpost was underway.

An Expanding Focus

Between 1966 and 1970, all the first and second stages of the Saturn V rocket used for the Apollo missions were test fired at the Mississippi Test Facility. When the Apollo era drew to a close in the early '70s, the Mississippi Test Facility entered a tran-►

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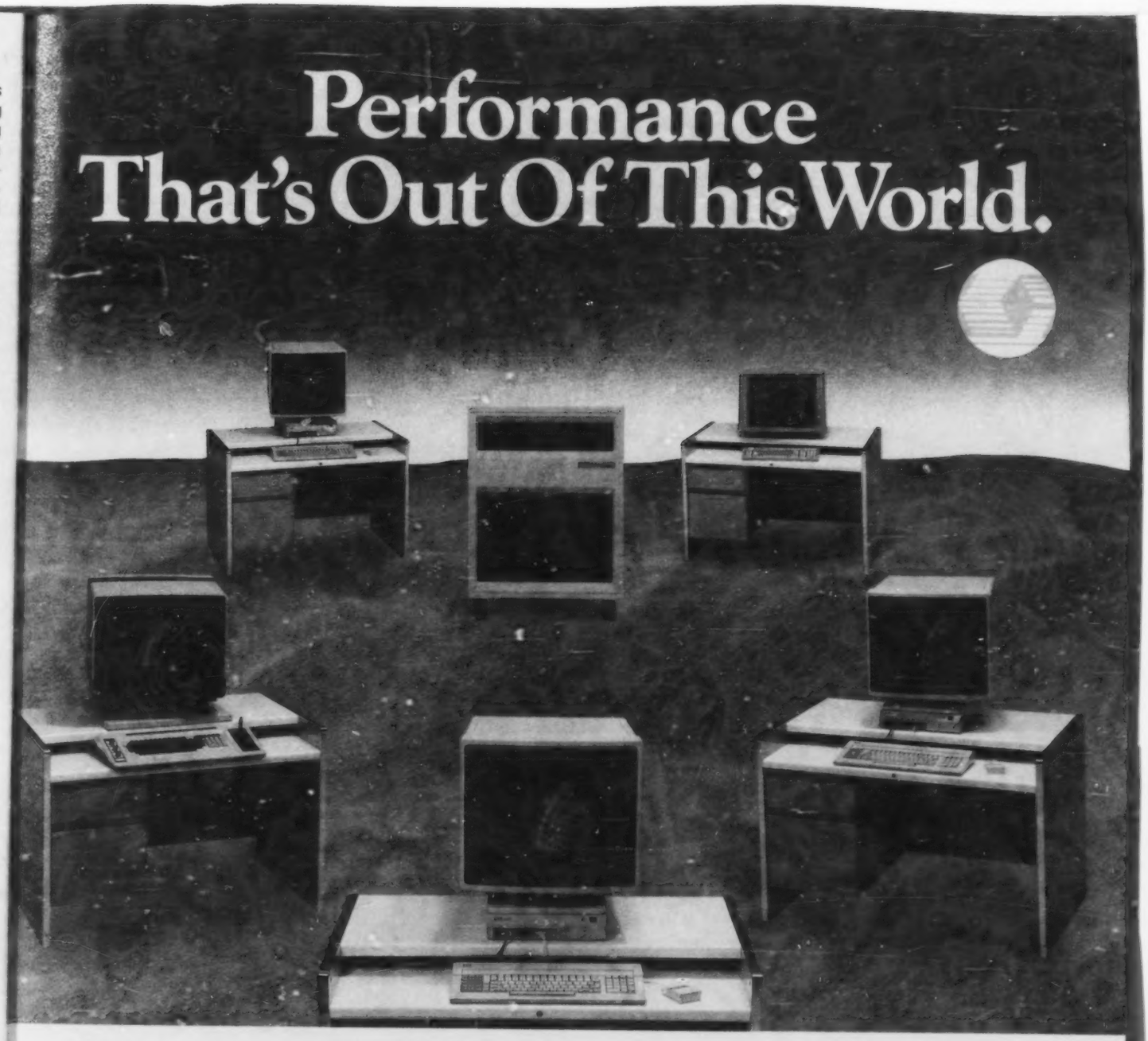

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In 1992, we set sail for a New World.

In 1492, a Spanish navigator and an intrepid crew sailed uncharted waters in search of a short passage to India. In the process, they discovered the vast resources of two new continents. And they established a new base for exploration, progress, and the future of mankind.

In 1992, on the 500th anniversary of Columbus's voyage, we plan to set sail for another New World. That year, or shortly thereafter, the United States and the world will begin benefiting from the first manned Space Station. The Station will be more than another giant step for mankind. It will be our stepping stone to living in new realms, and it will result in thousands of discoveries that will benefit earth.

This New World, free from gravity and atmospheric impurity, will provide that ideal environment for experimentation and production that is impossible on earth. Simultaneously, we will have a permanent station for scanning the earth and the heavens — an unparalleled vantage point for predicting weather, aiding agriculture, and understanding the universe.

Of course, like Columbus, we cannot foresee all the benefits ahead. But we do know that we will have a new arena in which to conquer disease, transform the materials of earth, and generate precious energy. The resulting knowledge from countless discoveries will come down to earth for our well-being.

But, unlike Columbus, our craft will be in constant contact with the Old World. Harris Aerospace, as a member of the Rockwell, Grumman and Sperry team, is responsible for the Space Station's communications and tracking system. We are totally committed to this great endeavor, and we are up to the challenge the capabilities and [illegible]

Harris has had 27 years of successful involvement with the kind of space communications and tracking required for the manned Space Station. Our space experience includes programs from Telstar to the Tracking and Data Relay Satellite as well as the manned programs of Apollo, Lunar Module, and Space Shuttle. We are also a leader in the architecture and design of large communication networks.

Now Harris is ready for the Space Station. Over the next years and centuries, the scope of scientific, commercial and technological opportunities and breadth of results are sure to exceed our wildest expectations.

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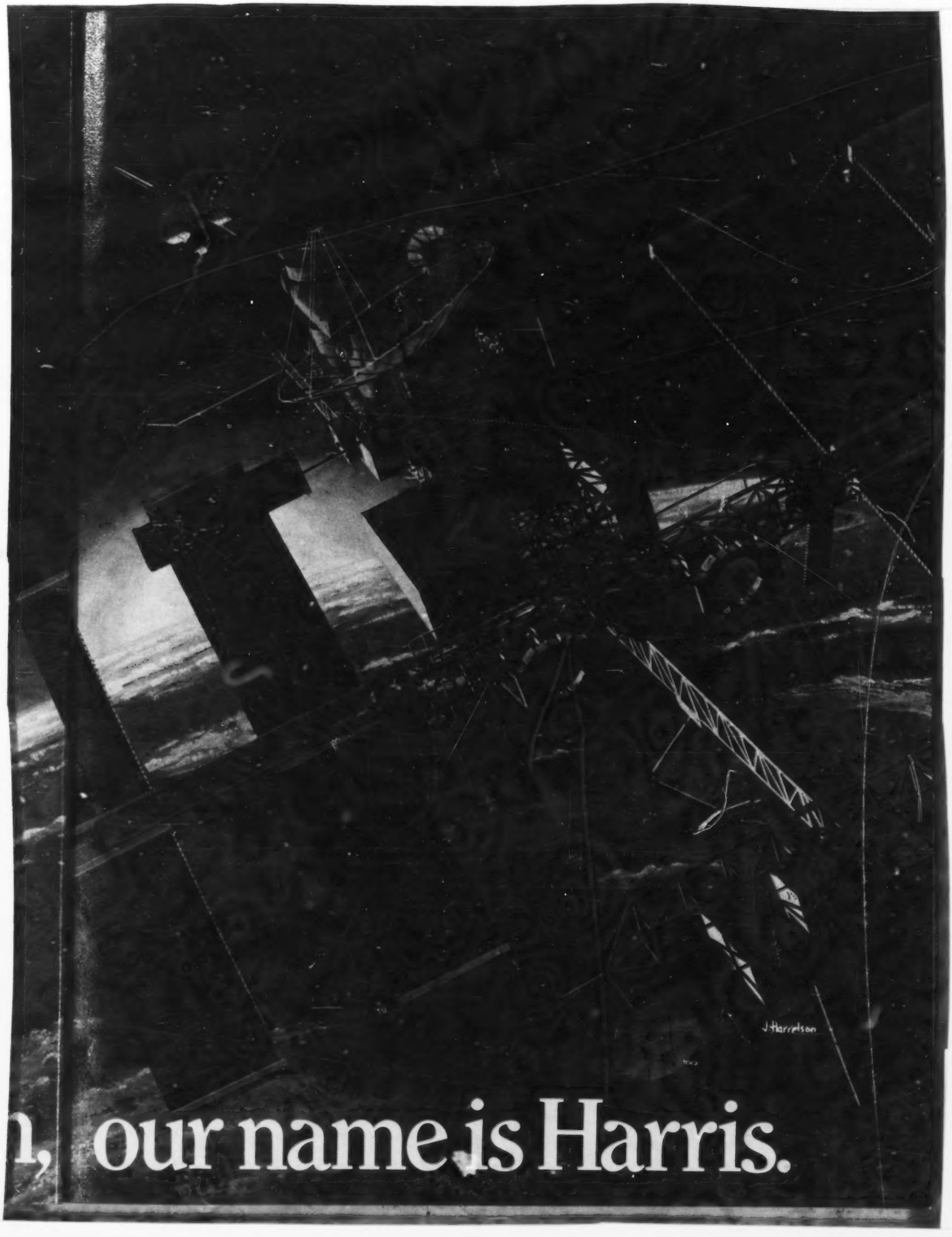

n, our name is Harris.

NSTL

sitional phase. Before the decade was out, the southern Mississippi site would metamorphose yet again, this time from a single-agency, single-mission test facility into a multi-agency, multi-mission federal laboratory. Highlighting all this was a simple name change. In 1974, the Mississippi Test Facility was renamed the National Space Technology Laboratories (NSTL) and given full NASA field center status.

At about the same time test engineers wrapped up their initial Saturn V assignment, NASA selected the facility to test the space shuttle's main engines and main propulsion system. Since the actual testing would not take place for several years, NASA began searching for ways to keep its $350 million facility economically and technically viable in the interim. In its characteristically innovative way, NASA succeeded in finding not one, but two solutions.

The first solution was to locate NASA's newly-established Earth Resources Laboratory at NSTL. This enhanced NSTL's technical and scientific base, and obviated the need for new construction or facilities. In 1970, NASA's Earth Resources Laboratory took up residence at NSTL, and research and development of space-related technology for earth observations got underway. Remote sensing and data systems development were designated as the primary research focus of the lab, and an applications program revolving around earth science disciplines—forestry, ecology and geology among them—was instituted alongside the R&D program.

The second solution involved opening the gates of NASA's southern Mississippi "city" to other federal agencies. In exchange for paying part of the cost of maintaining and operating the facility, other federal agencies could take advantage of the site's resources and NASA's support service contracts without incurring any long-term liabilities. NASA, in turn, agreed to act as mayor and city council of NSTL by supplying technical and installation support services to resident agencies.

Federal and state agencies alike took NASA up on its offer, and by the time NSTL had geared up for its primary mission—testing the shuttle main engines and main propulsion system—the Navy, the Army, the Department of Commerce and the Department of Interior, among others, had established offices at NSTL.

Full Steam Ahead

The transitions that occurred at NSTL during the '70s defined the center's agenda for the '80s, pointing up three distinct missions for the facility—space shuttle main engine testing, research and development of remote sensing technology and applications, and acting as a host agency in managing the installation. Activities in all three areas have expanded in recent years. ►

Building High Technology from the Ground Up

Because it can clog lakes and streams, the prolific water hyacinth was once considered a nuisance. A new bio-technology casts the aquatic plant in a beneficial role.

NSTL senior research scientist Dr. B.C. Wolverton will will show you a slide of a grazing goat and laughingly say, "NASA—high technology." Although he's laughing, Dr. Wolverton is not kidding. For the past 12 years, he and his associates at NSTL have been applying natural biological processes in solving a variety of environmental problems. The goat represents one harvesting option for NASA's plant-based, wastewater purification program.

The development of this innovative NSTL bio-technology began with the discovery that the roots of the water hyacinth, a vascular aquatic plant common in the South, are ideally suited for removing excess nutrients and organics from over-enriched lakes. Dr. Wolverton first applied the experimental water hyacinth technology in the sewage lagoon at NSTL. Racks of floating water hyacinths were placed in the 40-acre lagoon. The result? The roots of the water hyacinths absorbed the lagoon's excess nutrients, the plants themselves thrived (to the point where they required harvesting—enter the goats), and the lagoon was purified. The success of this original application paved the way for others, among them a wastewater purification system for the city of San Diego, California.

A serious water shortage prompted the city of San Diego to investigate methods of reclaiming potable water from sewage. In 1981 the city built an experimental wastewater purification system based on the NSTL water hyacinth technology. The success of the experimental system, which treated 25,000 gallons of sewage a day, inspired the city to build a one million gallon per day facility in 1984. This new facility combines water hyacinths with a new NSTL-developed reed/rock filtration system, or artificial marsh, for wastewater purification.

Several southern towns, the New Orleans Nature Center, and Walt Disney World's EPCOT Center also utilize the NSTL plant-based purification systems, either for wastewater treatment or experimental purposes. Individual homeowners can construct aritificial marshes in lieu of septic tanks for sewage treatment. Recently, the technology has been applied in removing chemicals and heavy metals from industrial wastewaters, and for purifying the water used in seafood processing.

Another focus of the NSTL environmental research is the problem of indoor air pollution, particularly in buildings which have been sealed for energy efficiency. Again, plants are the basis of the purification system, but in this case, the leaves rather than the roots do the work. Dr. Wolverton and associates determined that, in addition to carbon dioxide, plant leaves will remove harmful gases, such as benzene and formaldehyde, from the indoor environment. By pulling air through a plant-filled greenhouse, homeowners can ensure that their sealed homes are healthful as well as energy-efficient.

The ultimate application for NASA's plant-based purification technology will be the space station. Because it will be a closed system with no direct source of air or water, methods for recycling these elements will be extremely important. But for now and for years to come, this technology promises to be quite useful and beneficial right here on earth. □

The NSTL-developed reed/rock filtration system is applicable in colder climates which are inhospitable to the semi-tropical water hyacinth.

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NSTL

so that today NSTL is a fully-utilized, multi-mission facility.

NSTL's primary mission is to provide operational and technical support in the testing of the shuttle main engines and main propulsion system. NASA's Marshall Space Flight Center in Huntsville, Alabama, has design and development responsibilities for the shuttle main engines. A group of Marshall engineers is in residence at NSTL to monitor the tests, which are conducted by the engine private contractor, Rockwell International, Rocketdyne Division. NSTL's responsibility is to provide facilities, properly maintained and properly configured, and any and all technical support services required to test the engines.

In the beginning, this involved modifying one of the test stands to incorporate a simulated orbiter aft section, which holds the shuttle three main engines, and an external fuel tank, which feeds propellants to the engines. The propellants, liquid oxygen and liquid hydrogen, are ferried from New Orleans via NSTL's nine barges and NASA's only tugboat, the Clermont II. The barges store the propellants as well, and they're moored in the canals adjacent to the test stands. During tests, the barges service the test stands' run tanks with fuel as needed.

NSTL's 64 million gallon reservoir is connected to the test stands by pipelines 96 inches in diameter. During test runs, the reservoir supplies 300,000 gallons of water per minute at 200 psi to the stands for cooling. The reservoir also functions as a source of power generation.

Tests on both single shuttle engines and the three-engine cluster that, in conjunction with the solid rocket boosters, powers the shuttle during flight are conducted at NSTL. The initial R&D testing began in 1975, and today the emphasis is on increasing the engine's thrust level to 109%, meaning that each engine will generate 417,300 pounds of thrust at sea-level during liftoff. To date, shuttle engines have been tested for an accumulated 172,000 seconds at NSTL, or the equivalent of 340 launches.

Beyond the initial certification and flight acceptance testing, reacceptance tests are also conducted at NSTL. After an engine reaches the end of its mission life, it is returned to NSTL for reacceptance testing before being sent back to the Cape for reuse.

Unlike the Saturn V rockets that preceded them, the shuttle engines are relatively good neighbors. Although they're nearly as loud, the fuel that powers them produces a nice, clean steam. And while the gargantuan Saturn rocket engines were Cleopatras of a sort, coming and going on barges, the smaller shuttle engines are transported over land by trucks.

"Over land" brings up the second of NSTL's three missions, conducting research and development of remote sensing technology for use here on earth. NSTL's Earth Resources Laboratory applies its efforts in three areas—earth science and applied research and commercialization, with supporting sensor and data systems engineering.

The Earth Resources Laboratory's science program focuses on the physical, biological and chemical processes occurring in tropical forests and aquatic ecosyterns. The ERL is working cooperatively with the academic community to form a better understanding of these processes in the role that remote sensing will play in future global monitoring and assessment.

The lab's applied research and commercialization program is working with the private sector and medical community to develop remote sensing techniques for use in earth resources assessments and medical diagnostics.

NSTL's Earth Resources Laboratory is also supporting NASA's space station program, both in terms of finding potential commercial sponsors for earth and ocean observation missions on the space station, and in developing data systems that simulate space station payloads. In the commercialization function, the laboratory is supporting one of NASA's five Centers for the Commercial Development of Space. The Space Remote Sensing Center was established at NSTL earlier this year by Mississippi's Institute for Technology Development. The Center will be developing applied research programs and, with industry, joint research projects that exploit the commercial applications of remote sensing technology, whether in land or resource management, or medical and scientific applications.

The laboratory's data systems engineering group designs and develops ground data processing and analysis systems that handle the massive amounts of data transmitted by remote sensors. The engineering group supports the laboratory's science and applied research and commercialization programs, in addition to developing and managing the entire NSTL automated data processing capability.

Supplying data processing capabilities to the entire facility is one aspect of NSTL's third mission—to manage the installation and provide technical and support services to the site's 17 resident agencies. Another aspect of this mission is the cooperative programs that have grown out of NSTL's unique arrangements with its resident agencies. For example, the Earth Resources Laboratory's data systems engineering group is upgrading the data analysis system that the U.S. Navy uses to guide its fleet of ships. This arrangement

After powering Atlantis on its maiden flight, this shuttle main engine is back at NSTL for recertification tests.

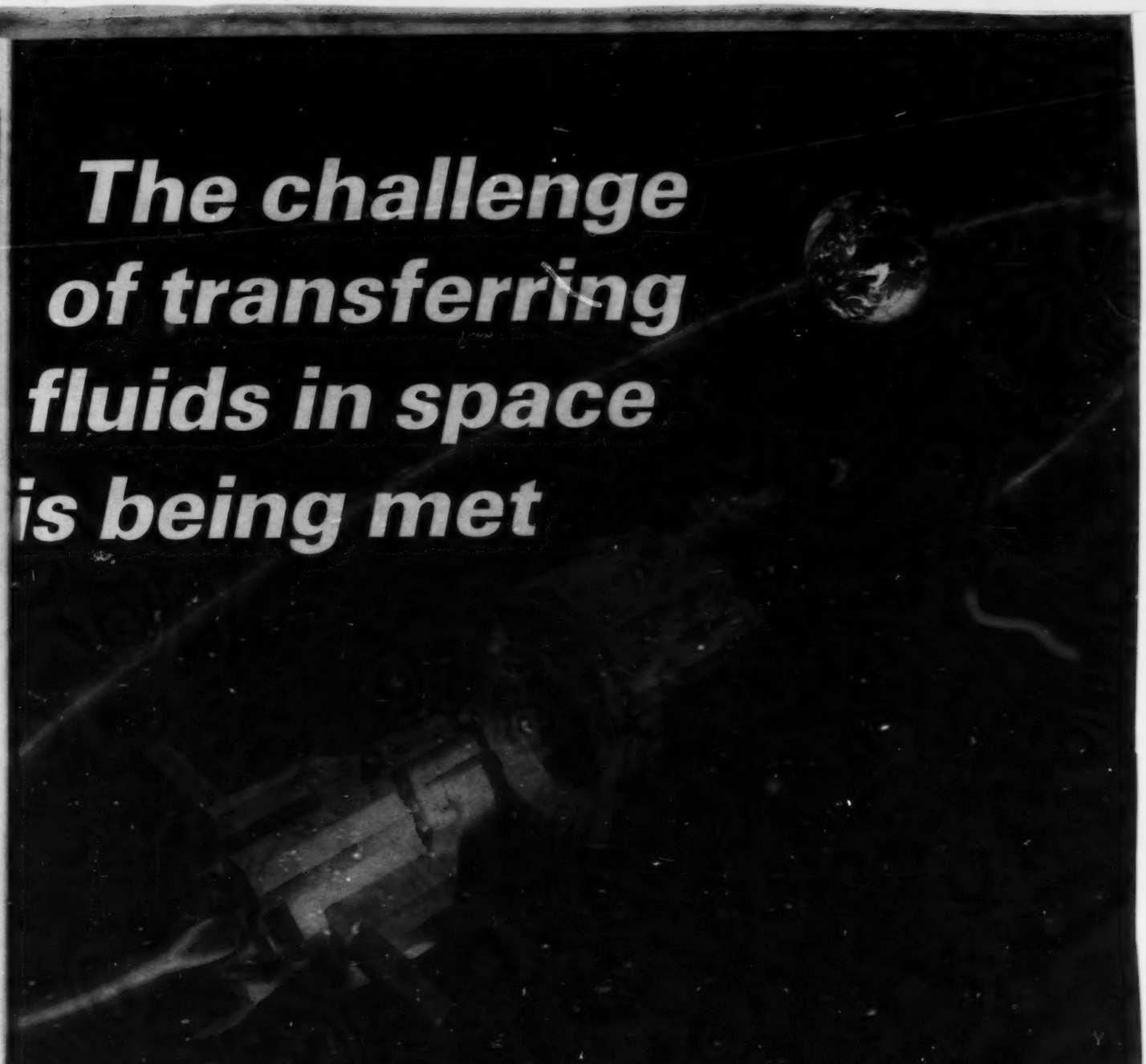
was sparked by the presence of the Navy's Oceanographic Command at NSTL.

This sort of interactive utilization of technology and resources has attracted two state agencies to NSTL. Both Louisiana and Mississippi have established technology transfer offices at NSTL, with the aim of improving the productivity and economic viability of their industries. Mississippi, widely perceived as the poorest state in the nation, has made a substantial commitment to utilizing technology for economic development. In 1985, the state appropriated $4 million for the construction of a new building at NSTL. When completed, it will house new federal agency personnel and various state agency offices. It is anticipated that the state will profit from its investment by utilizing advanced technology to foster industrial expansion and economic growth.

In the words of Dr. James Miller, director of the Mississippi Technology Transfer Office, "Mississippi is making a concentrated effort to link its economic future to people-based industry," most of which is founded on high technology. Its linkage with NASA is part of a cohesive array of initiatives that will bring Mississippi from the agricultural phase straight into the information age. According to Dr. Miller, the initiatives are designed not to help Mississippi catch up with the rest of the country, but to help it leap ahead.

It's still too early to tell just how well Mississippi's plan will work, especially since its home base, the new NSTL building, is still under construction. But as a point of departure, the far-reaching plan to bolster economic development through high technology sounds promising. Mississippi, it seems, has a lot to look forward to, and the rest of us, well, we may just learn a thing or two from our enigmatically high-tech Southern cousin. □

The challenge of transferring fluids in space is being met



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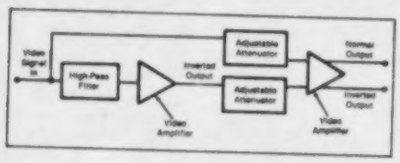
New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 29). NASA's patent-licensing program to encourage commercial development is described on page 29.

Analog Video Image-Enhancing Device

A real-time analog video image-enhancing device improves the appearance of technical photographs by selectively compressing their overall dynamic ranges while accentuating edges or small details of greatest interest. The system includes a video camera connected to a video monitor to which a circuit (see figure) is added for analog video enhancement. The video signal is high-pass filtered, amplified, and then added in a second video amplifier to the unfiltered signal; the sum is sent back to the monitor. Black-and-white reversal is possible in the second amplifier, allowing negatives as well as prints to be examined directly. Adjustments of the new image parameters along with the conventional variability of monitor brightness and contrast allows a wide range of image enhancement. In addition, the time constant on the high-pass filter results in a pseudo-three-dimensional effect, which sometimes shows detail more clearly.

(See page 46.)



Measuring Thicknesses of Coatings on Metals

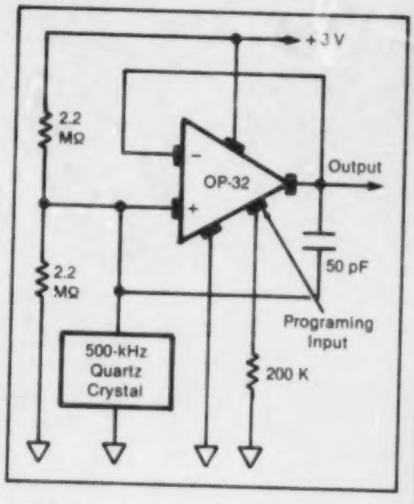
Using laser-beam reflections and eddy-current sensing, an instrument measures the thicknesses of nonconductive coatings on metal substrates; the eddy-current sensor maintains a reflected-light triangulation sensor at a fixed distance from the surface of the substrate as the substrate moves under it, while the light sensor determines the angle and therefore the perpendicular distance of the laser-beam spot on the coating surface. When the capabilities of available components are fully exploited, the instrument will be able to measure coatings from 0.001 to 6 in. (0.0025 to 15 cm) thick, with an accuracy of 1 part in 4,000. The instrument can readily be incorporated in automatic production and inspection systems; for example, it can be used to inspect thermal insulation layers, paint, protective coatings, or to control the application of coatings to preset thicknesses.

(See page 94.)

Temperature-Sensitive Oscillator

A quartz-crystal oscillator—the frequency of which depends on its temperature— serves as a small, inexpensive, low-power, temperature-sensing circuit that can be used as an ingestible thermometer for measuring internal body temperature. Because the circuit does not depend on any temperature sensitivity of the crystal itself, readily-available, inexpensive crystals can be used. The circuit also avoids the linearity and stability problems of thermistor-based temperature-sensing circuits. The oscillator operates at about 500 kHz, a frequency that is readily transmitted through the body. With the component values shown in the figure (OP-32 is a high-gain, programable operational amplifier), the change of capacitance with temperature causes the oscillator frequency to increase linearly, at about 4 Hz per °C, over the temperature range of 30 to 40 °C.

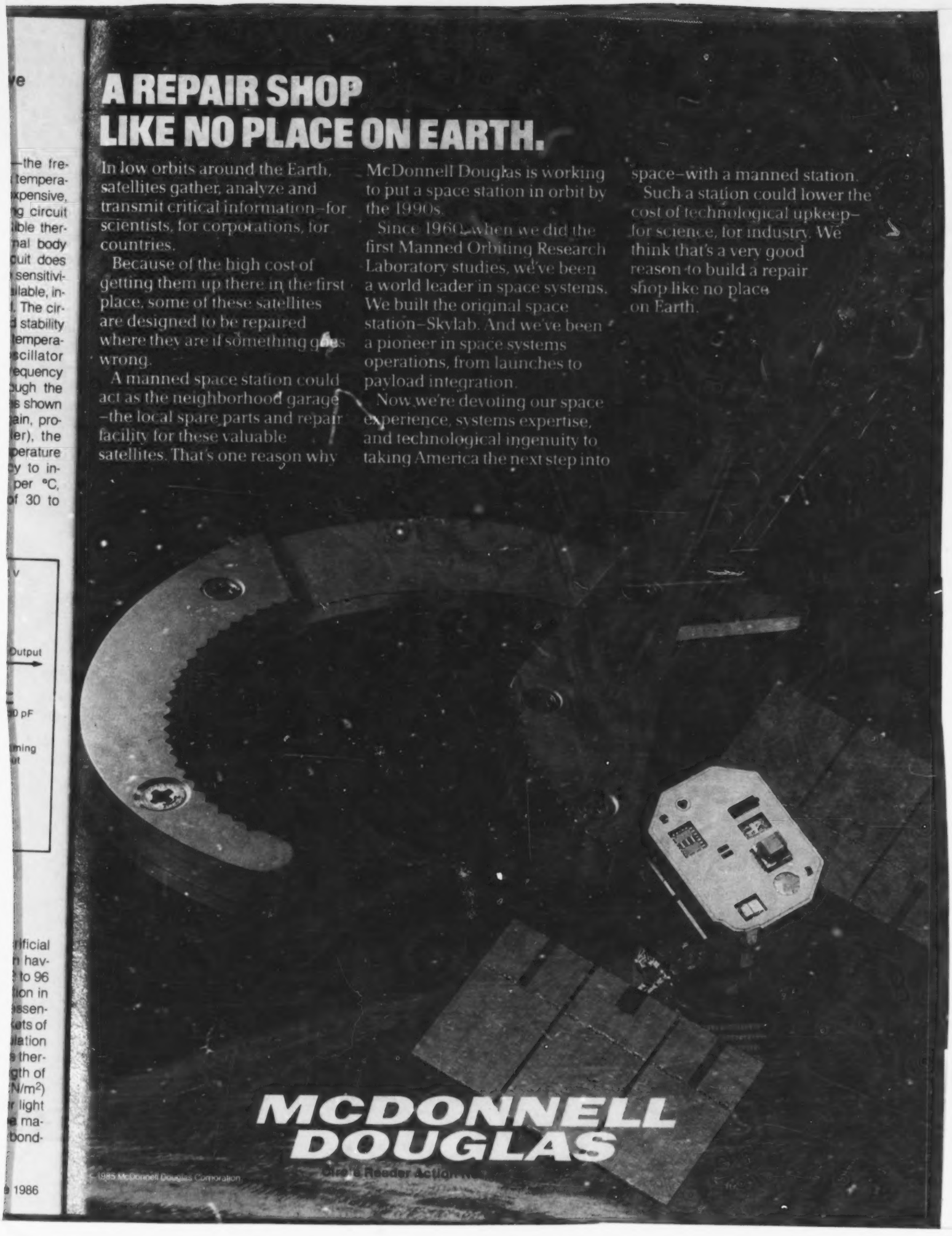
(See page 39.)



Lightweight Ceramic Insulation

Prepared by a process of sacrificial burnout, a rigid ceramic insulation having a low density of 2 to 6 lb/ft^3 (32 to 96 kg/m^3) can replace flexible insulation in applications where low weight is essential. Unlike the loose fibers or blankets of flexible insulation, the new insulation does not pack together or shift. It is thermally stable, and its flexural strength of 25 to 75 lb/in.^{2} (170 to 500 kN/m^2) enables it to retain its shape under light loading. The rigid insulation can be machined to the requisite shape and bonded.

(See page 65.)


A REPAIR SHOP
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In low orbits around the Earth, satellites gather, analyze and transmit critical information–for scientists, for corporations, for countries.
Because of the high cost of getting them up there in the first place, some of these satellites are designed to be repaired where they are if something goes wrong.
A manned space station could act as the neighborhood garage –the local spare parts and repair facility for these valuable satellites. That's one reason why McDonnell Douglas is working to put a space station in orbit by the 1990s.
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The Most Accurate 20MHz Logic Analyzer Available For Only $1,495.

Only with the Logic-20™
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With a set-up time of only 2 ns., the Logic-20 from BitWise Designs blows away its nearest 20 MHz competitors — which are totally unreliable for a monstrous 25 ns. before the clock edge.

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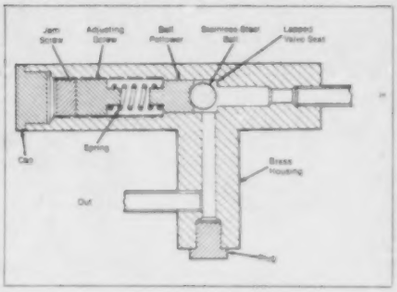
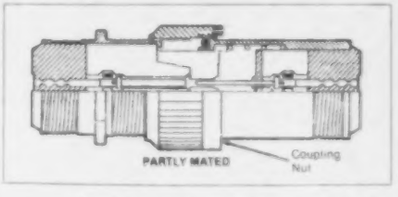
Spring-Loaded Joule-Thomson Valve

A spring-loaded Joule-Thomson (J-T) valve (see figure) permits optimal cooling-power regulation of a helium refrigerator by allowing independent adjustment of the flow rate and pressure drop through the valve. Because the spring-loaded J-T valve maintains a constant pressure drop, an upstream room-temperature throttle valve can adjust the flow rate precisely for any given upstream pressure, even while the helium is flowing. In addition, the new valve is relatively invulnerable to frozen gas contaminants, which can clog fixed-opening J-T valves.
(See page 101.)

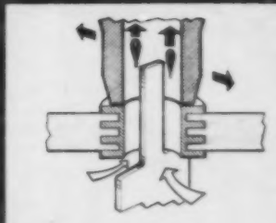


Self-Alining Electrical Connector

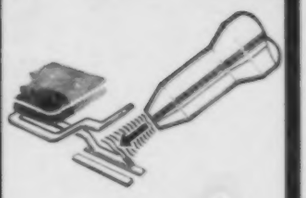
A self-alining, multipin electrical connector prevents the breaking or bending of male pins that occurs with conventional connectors when misalined contacts are carelessly pressed together. The new design features tapered insulators that are keyed to mate each other before the male pins touch the female sockets. The contacts mate when the coupling nut draws the alined plug and socket together, depressing one of the alining insulators against a spring. The compressed spring applies tension on the mated threads of the assembly, helping the connector resist loosening under vibration or shock. This connector should be particularly useful in locations that are out of sight or difficultly accessed. The design could also be useful in high voltage applications because the mating insulators eliminate air spaces that could otherwise become electrical-leakage pathways.
(See page 33.)



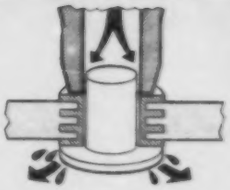
REPAIR PCB'S



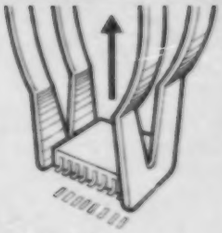
Spike Free
Vacuum Desoldering



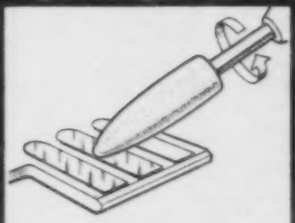
Hot Air Jet
Flat Pack Removal



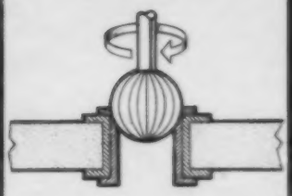
Blind Joint
Pressure Desoldering



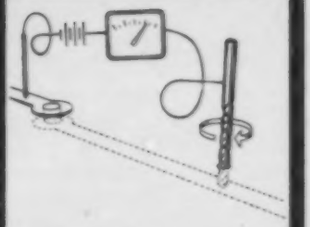
Multi-terminal
Chip Removal



Precision Abrading
Thin Coatings

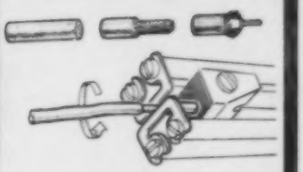


High Torque - Low RPM
Drilling and Milling

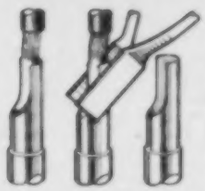


Drilling Test Probe
Spike Free

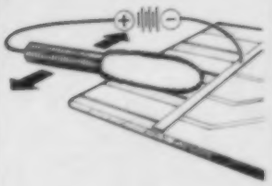
Conforming
Coating Removal



Thermal Stripping
Coax and Teflon



Resistance Soldering
Cup Terminals



Gold Plating
Edge Connectors

Lapflow Soldering
Circuit Repair

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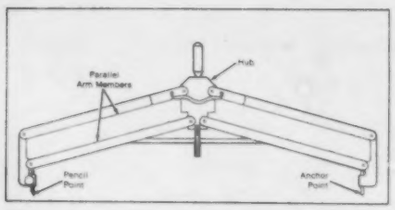
Parallel-End-Point Drafting Compass

A drafting compass employs a parallelogram linkage between its ends and its hub to keep its pointed ends in parallel when it is closed, when it is fully open, and at all positions in between (see figure). A pair of omega-shaped springs secures the linkage arms in the position set by the user until the user readjusts the end spacing. The parallelogram-linkage principle can be used on dividers as well as on compasses. When the pointed ends are in parallel, distance measurements become more precise than with inexpensive compasses or dividers that have their pointed ends extending radially from the hub. At the same time, the new compass/dividers are more convenient than the more expensive compasses and dividers that have adjustable points that have to be set individually for each new radius to keep the pointed ends in parallel.

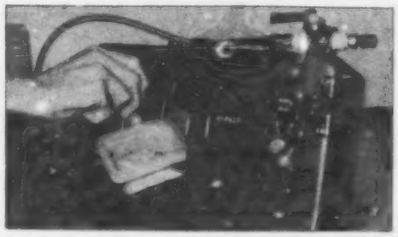
(See page 103.)



Small-Portion Water Dispenser

A dispenser provides a measured amount of water for reconstituting dehydrated foods. The dispenser holds the food or beverage package while it is being filled with either cold or room-temperature water (see figure, which shows the dispensing needle about to penetrate a plastic food package). Other uses might include the dispensing of fluids or medicine. A pressure regulator in the dispenser reduces the varying pressure of the water supply to a constant pressure. An electronic timer stops the flow after a predetermined length of time, ensuring that a controlled volume of water is dispensed.

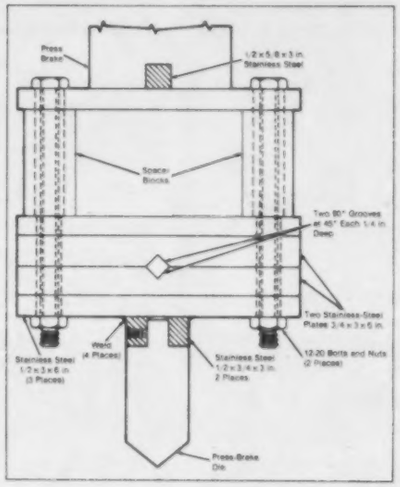
(See page 152.)



Adjustable Tooling for Bending Brake

An adjustable tooling jig for a bending-brake accommodates spacing blocks and either a standard male press-brake die or a bar die. By increasing the free space available for bending sheet-metal parts, the jig makes it easier to fabricate such items as deep metal boxes or brackets with right-angle bends. To make deep metal boxes, the jig is interposed between the press brake and one of the press-brake dies; spacer blocks are fabricated to the required dimensions as needed by cutting them from metal scraps. To fabricate smaller parts with multiple right-angle bends, the press-brake die is removed from the bottom of the jig, and a round or square bar is clamped between the upper and lower 90° grooves. The bar then serves as the male bending die, cooperating with a female die consisting of a grooved block placed on the lower press-brake surface.

(See page 124.)


Press Brake
Spacer Blocks
Two 90° Grooves at 45° Each 1/4 in. Deep
Two Stainless-Steel Plates 3/4 × 3 × 6 in.
Weld (4 Places)
Stainless Steel 1/2 × 3 × 6 in. (3 Places)
Stainless Steel 1/2 × 3 1/4 × 3 in. 2 Places
1/2-20 Bolts and Nuts (2 Places)
Press-Brake Die

Material for Fast Cutting

A new material based on silicon nitride and containing more than 90 percent silicon combines impact resistance close to that of coated carbides with heat and wear resistance close to those of aluminum oxide ceramics. Because tools made of this material can operate at relatively high cutting speed, they will remove more material than will a conventional tool operating at the same pressure. Consequently, a high removal rate can be accomplished with relatively low pressure, which greatly reduces vibration, workpiece slippage, and tool breakage. With its relatively long life, this material reduces the amount of cutting time lost to indexing, gauging, and adjustments.

(See page 70.)

Rotating Apparatus for Isoelectric Focusing

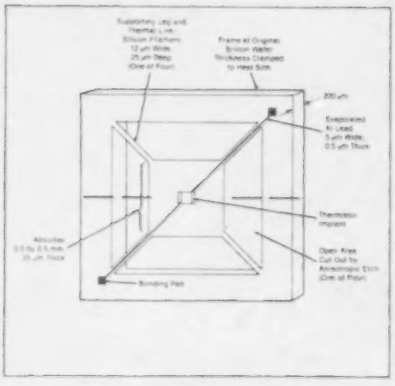
An improved isoelectric focusing apparatus helps to prevent electro-osmosis and convection, both of which cause the remixing of separated fractions. The apparatus is slowly rotated continuously or rocked about its horizontal axis at a rotational amplitude of at least 180° so that the average gravitational vector experienced by the fluid is zero, and the convection is therefore suppressed. Use of filters to separate the column into dislike compartments along its length further suppresses convection and suppresses electro-osmosis. Experiments have shown that the dimensions of the apparatus are not critical. Typical compartment and column volumes are 2 and 40 ml, respectively. Rotation speeds can lie between 3 and 30 rpm.

(See page 152.)

High-Resolution Thermal X-Ray Detector

A thermal X-ray detector, tested successfully in prototype, in theory can operate as a spectrometer with a resolution less than 5 eV full width at half height — 100 times the spectral resolution of conventional solid-state detectors — with high efficiency from 100 eV to 9 keV. It could be used to detect trace constituents in minerals by X-ray fluorescence. It also could be used for measuring the energies of energetic electrons and weak pulses of light. The figure shows a version of the detector, which consists of an X-ray absorber, a temperature sensor in the absorber, and a thermal link from the absorber to a heat sink. An X-ray photon is detected by measuring the temperature rise immediately following the absorption of the photon.

(See page 37.)



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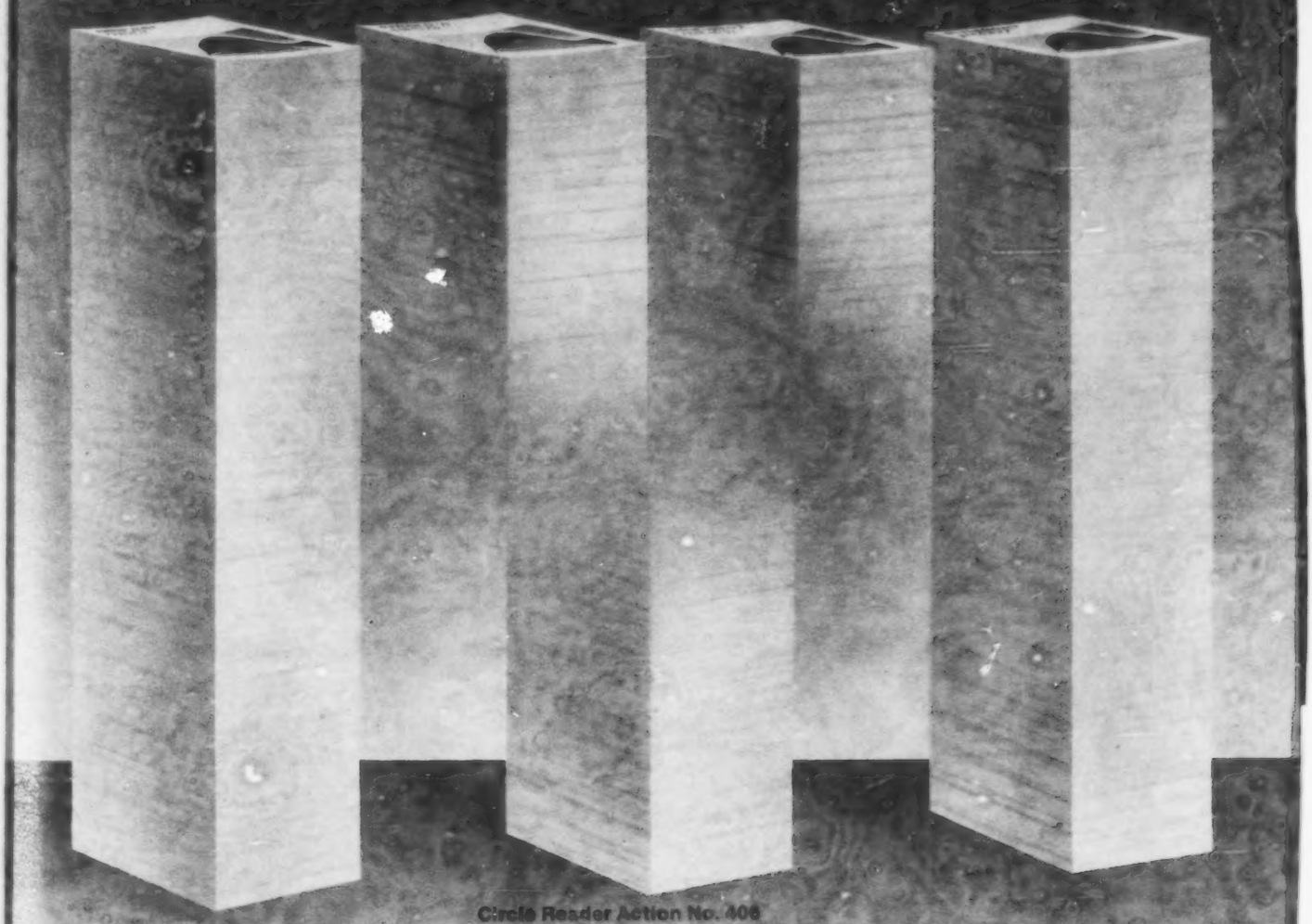

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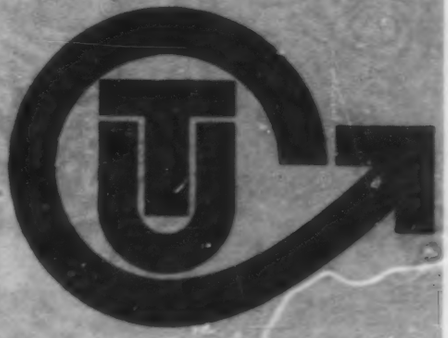

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On the following pages, we've outlined NASA's TU Network—named the participants, described their services, and listed the individuals you can contact for more information relating to your specific needs. We encourage you to make use of the information, access, and applications services offered by NASA's Technology Utilization Network. You can save time and money by doing so.

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If you represent a public sector organization with a particular need, you can contact NASA's Application Team for technology matching and problem solving assistance. Staffed by professional engineers from a variety of disciplines, the Application Team works with public sector organizations to identify and solve critical problems with existing NASA technology.

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If you need further information about new technologies presented in NASA Tech Briefs, you you should request the Technical Support Package (TSP) that accompanies the brief. In the event that a TSP is not available, you can contact the Technology Utilization Officer at the NASA Field Center that sponsored the research. He can arrange for expert assistance in applying the technology by putting you in touch with the people who developed it.

If you want additional information about the patent status of a particular technology or are interested in licensing a NASA invention, contact the Patent Counsel at the NASA Field Center that sponsored the research. Be sure to refer to the NASA reference number at the end of the tech brief.

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Patent Counsel:
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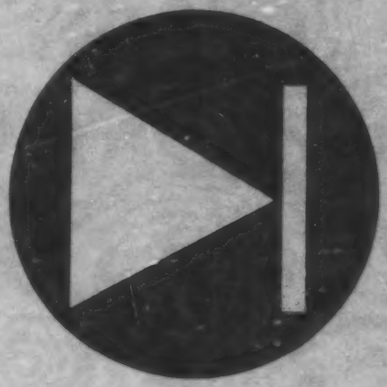
Electronic Components & Circuits



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Fabrication of an X-Ray Imaging Detector

A silicon wafer would be divided into an array of X-ray detectors.

Goddard Space Flight Center, Greenbelt, Maryland

An X-ray detector array that could yield a mosaic image of an object emitting in the 1- to 30-keV range could be fabricated from an n-doped silicon wafer. The detector is an improved version of the device described in "X-Ray Detector for 1 to 30 keV" (GSC-12682), *NASA Tech Briefs*, Vol. 7, No. 3 (Spring, 1983), page 248.

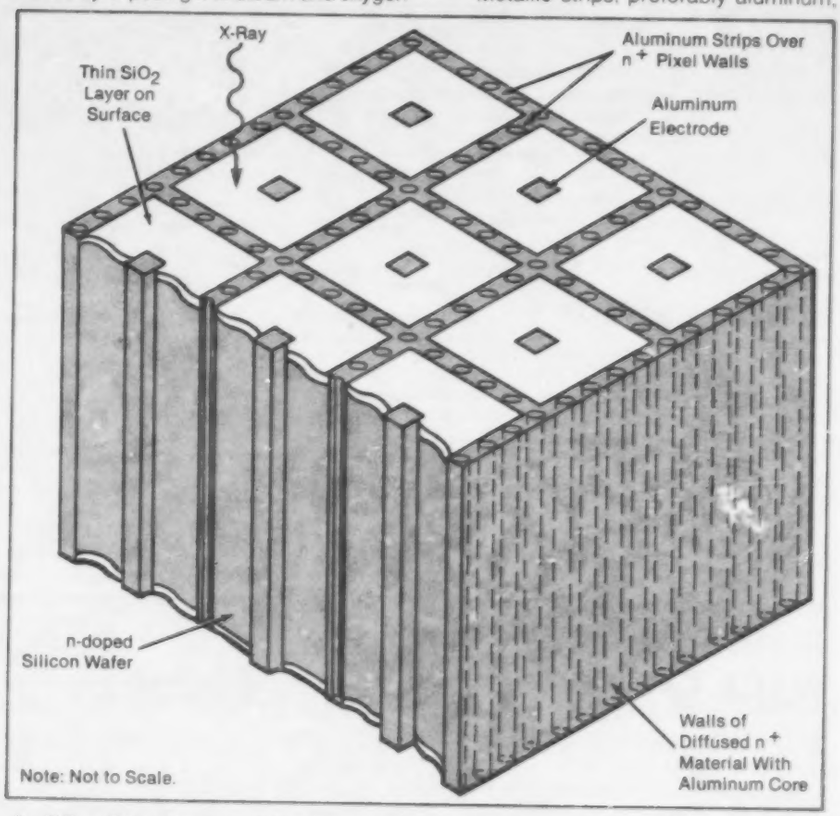
In the proposed fabrication technique, thin walls of diffused n^+ dopant would divide the wafer into pixels of rectangular cross section, each containing a central electrode of thermally migrated p-type metal. This pnn^+ arrangement would reduce the leakage current by preventing the transistor action caused by the pnp structure of the earlier version.

The n-type conductivity in the silicon wafer would be produced by doping it lightly with phosphorus. For 1- to 30-keV X-rays the wafer thickness would be about 50 mil (1.27 mm). Relatively thin layers (about 2,000 Å thick) of silicon dioxide would be formed on the wafer surfaces by exposing it to steam and oxygen while its temperature is maintained at about 1,000 °C.

In the first step in the pixel formation, a photoresist mask is applied to the upper surface of the wafer to delineate the walls. The surface is etched in a buffered hydrofluoric acid solution to remove selectively the upper silicon dioxide layer in a pattern defining the pixel walls.

A laser is used to drill circular openings, about 1 mil (0.025 mm) in diameter, centered every 2 mil (0.05 mm) along the etched pattern and passing perpendicularly completely through the wafer. The wafer, placed in a furnace at 1,100 °C, would then be exposed to a phosphorus gas dopant ($POCl_3$ in a mixture of gaseous nitrogen and oxygen) for a time sufficient to assure diffusion of the dopant atoms to a distance of 1 mil (0.025 mm) from the axis of each opening, the phosphorus atoms diffusing from adjacent openings thus coming into contact to produce continuous walls of n^+ atoms.

Metallic strips, preferably aluminum,


X-Ray
Thin SiO_2 Layer on Surface
Aluminum Strips Over n^+ Pixel Walls
Aluminum Electrode
n-doped Silicon Wafer
Walls of Diffused n^+ Material With Aluminum Core
Note: Not to Scale.

An X-Ray Detector Array fabricated from a single silicon wafer consists of pixels of n-doped silicon separated by n^+ walls and containing aluminum (p) electrodes.

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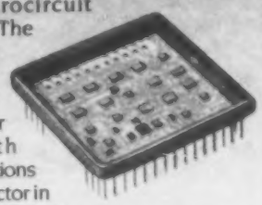

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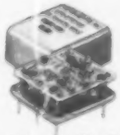

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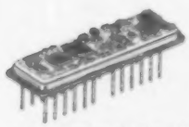

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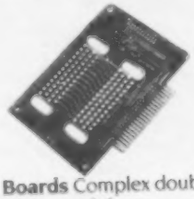

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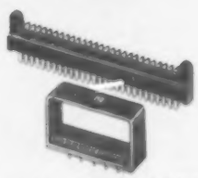

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would then be evaporated over the exposed wall areas of the top surface to contact the diffused phosphorus, forming the interconnected configuration shown in the figure. A similar array of aluminum strips, contacting the diffused phosphorus at the openings, would be produced evaporatively on the lower wafer surface.

To locate the thin aluminum electrodes centered in each pixel, a photoresist mask with openings at the pixel centers is applied to the upper wafer surface. The masked wafer is etched with hydrofluoric acid to expose the silicon in the center. Then, after the photoresist mask is stripped using hot chromic acid and the wafer rinsed clean, aluminum is evaporated over the top wafer surface. A second photoresist mask is then applied to protect the aluminum film at the future electrode sites while the rest of the film is etched with phosphoric acid.

After the second mask is stripped with chromic acid and the wafer rinsed clean, the lower surface of the wafer is heated to about 1,150 °C, while the upper surface is kept slightly cooler at about 1,100 °C. The resulting thermal gradient causes the aluminum deposited in the etched opening on the cooler surface to form the central electrodes by diffusing completely through the wafer to the opposite surface. The aluminum strips connecting the n^+-diffused regions also diffuse through the wafer to form aluminum walls between the pixels.

Since this rapid diffusion allows little time for lateral diffusion, the cross section of each electrode is small compared to the cross section of each pixel, thereby minimizing the probability of X-rays impinging directly on the central electrodes. To enhance the spatial resolution of an X-ray image, the horizontal cross section of each pixel is kept small: The separation between the central electrodes of adjacent pixels is about 1 mm.

The array of detector cells comprises a deep diode array, since both the n^+ pixel walls and the metal electrodes extend completely through the wafer. The application of bias potentials between the central electrodes and the walls creates a depletion region extending laterally from the central electrode to the walls of each pixel through the entire wafer thickness.

In this configuration, incident X-rays impinging on the wafer with a penetration depth less than its thickness; i.e., with energies up to 30 keV, precipitate photoelectron interactions with the wafer material. Regardless where the interaction occurs within a pixel, the resulting photoelectrons are attracted to the central electrode, thereby providing a signal for the detection of the incident X-rays. The central electrode of each pixel could be connected to a separate element of a

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charge-coupled-device processor, enabling the processor to read sequentially each pixel and generate a composite image of it as it appears on the illuminated surface of the detector array.

This work was done by George E. Alcorn and Andre S. Burgess of **Goddard Space Flight Center.** *For further information, Circle 82 on the TSP Request Card.*
GSC-12956

Self-Alining Electrical Connector

A mating pair of insulators forces the initial alinement of a plug and socket.

Marshall Space Flight Center, Alabama

A self-alining multipin electrical connector features tapered insulators that are keyed to mate each other before the male pins come into contact with the female sockets. This arrangement prevents the breakage or bending of the male pins as on conventional connectors when misalined contacts are carelessly pressed together.

In the new design (see figure), the male pins are recessed behind one of the alining insulators so that they cannot touch the female contacts before the plug and socket are properly alined. The contacts mate when the coupling nut draws the alined plug and socket together, depressing one of the alining insulators against a spring. The compressed spring provides tension on the mated threads of the assembly, helping the connector to resist loosening under vibration or shock.

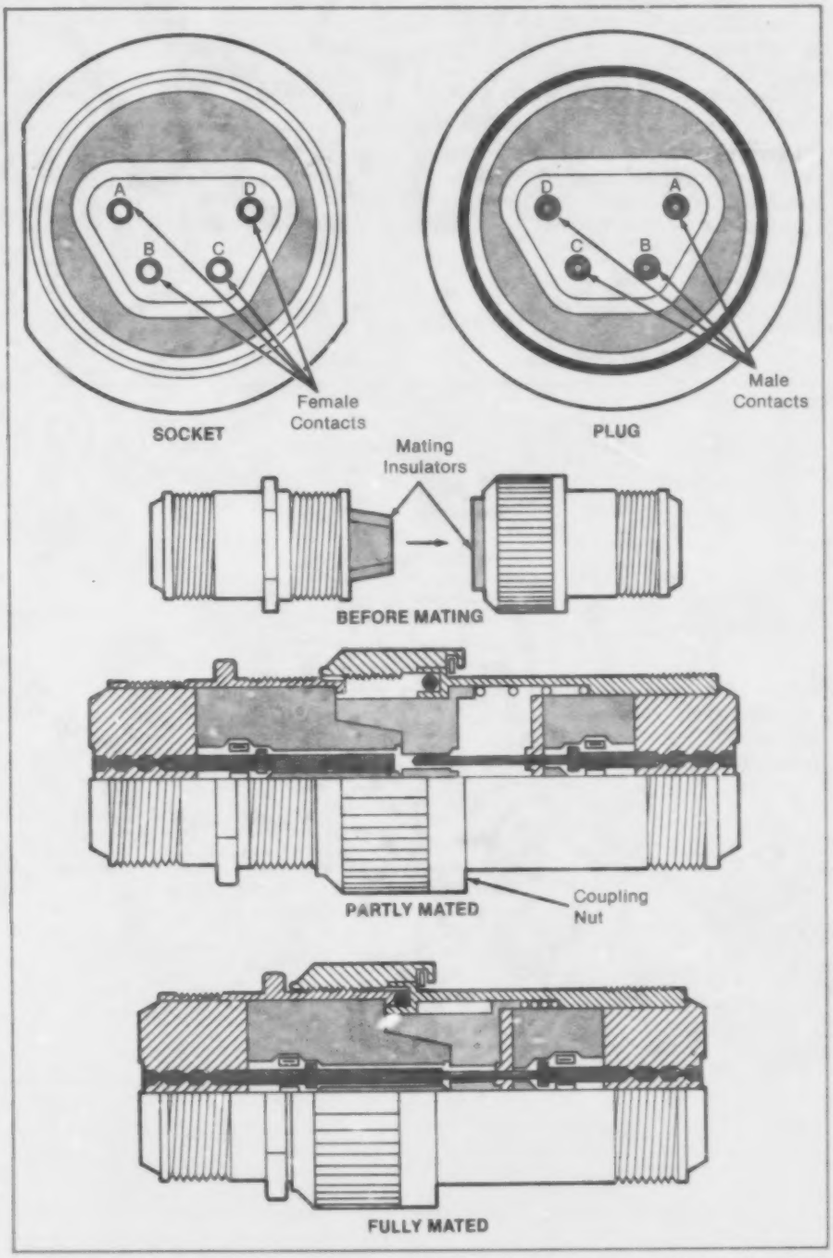
In contrast, conventional connectors must be alined precisely before the contact to prevent the pin damage. By providing the alinement before the mating, the new design effectively extends the contact life. Furthermore, the accurate alinement would simplify the mating of connectors having high contact densities.

The new connector should be both faster and easier to use than are conventional circular multipin connectors, particularly if the user is wearing gloves or the connector is located out of sight, in a confined space, or in a hard-to-reach location. The new connector concept could be used in fiber-optic connectors or in hybrid electrical/fiber-optic connectors.

Connectors embodying the concept can be packaged in housings suitable for such severe environments as high altitude, outer space, under water, high or low temperatures, or high pressures. The design would also be useful in high-voltage applications because the tapered alining insulators would press against each other when the coupling nut is fully tightened, eliminating air spaces, which could otherwise become electrical-leakage paths.

This work was done by Anthony Iwanic of Arbus, Inc., for **Marshall Space Flight Center.** *For further information, Circle 1 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-26022.



The **Plug and Socket** have tapered, trapezoidally shaped insulators, which guide alinement. Partially-cutaway side views show the connector pair at two stages in the mating process: In the first, the tapered insulators have touched and forced each other into alinement prior to contact mating; in the second, tightening the coupling nut on the plug has pushed the plug further into the socket, compressing the spring behind the plug insulator, and forcing the electrical contacts to mate.

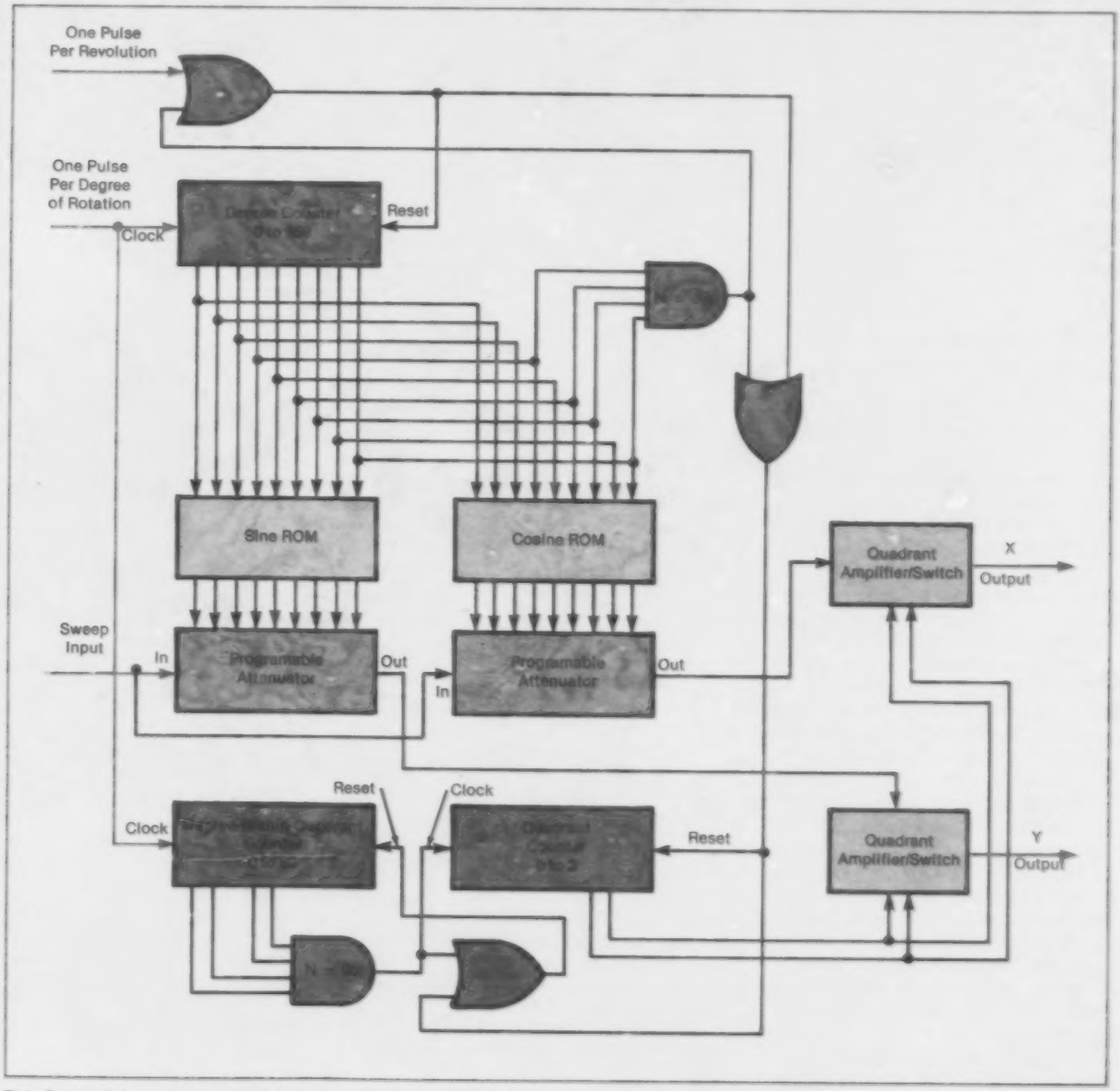
ROM-Based Plan-Position-Indicator Sweep Driver

The circuit produces a PPI display on a conventional X-Y oscilloscope.

Langley Research Center, Hampton, Virginia

The read-only-memory-based (ROM-based) plan-position-indicator (PPI) sweep driver electronically generates circular radar presentations on a conventional X-Y oscilloscope. Conventional methods to accomplish this task have used mechanically-driven deflection coils or mechanically-driven sine and cosine potentiometers, requiring mechanical preventive maintenance plus a dedicated display indicator. The new method can display the radar sweep on any conventional storage oscilloscope.

The ROM-based system uses a programable memory to define the sweep function. Because the sweep function thus becomes essentially a table-lookup function, other presentation formats can be accommodated by changing or electrically selecting different memory chips. For example, the normal search-radar



This **Sweep Driver** generates a PPI display on a conventional X-Y oscilloscope. The mechanically-driven deflection coils or potentiometers of prior PPI display units are not needed.

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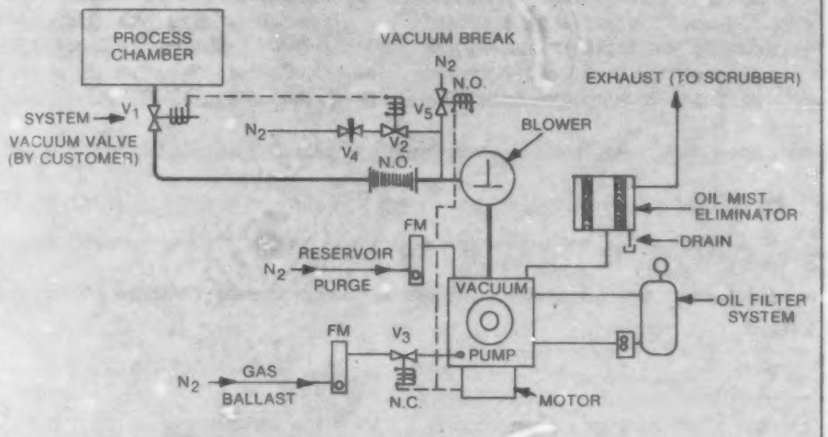

NOTES:
1. ALL NITROGEN GAS BLEEDS—1 PSIG MAXIMUM
2. SYSTEM VALVE V_1 INTERLOCKED WITH VALVE V_2. WHEN V_1 CLOSED V_2 OPEN. WITH V_1 CLOSED & VACUUM SYSTEM IN OPERATION, USE NEEDLE VALVE V_4 TO ADJUST PRESSURE IN MANIFOLD TO 50-100 MICRONS.
3. SOLENOID VALVE V_3 CONNECTED ACROSS MOTOR LEADS. OPENS WHEN PUMP STARTS.
4. FM = FLOW METER
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To keep your vacuum system performing to its capabilities, you must prevent water vapor from entering the system. If it does, you must remove it quickly.

The following installation and operation procedures will help you keep your system operating smoothly.

The right installation.

Install PVC exhaust piping instead of galvanized or black iron pipe, and an oil mist eliminator to reduce oil loss from the pump.

The exhaust line should be installed so it can easily be disassembled for periodic cleaning and the vacuum manifold must be leak-free.

The right operation.

Operate the vacuum system continuously and make sure the vacuum pump is gas ballasted during processing with a nitrogen flow rate of 1 to 2 L/M.

Purge the reservoir with nitrogen (in humid ambients it may be necessary to increase the nitrogen flow). Do not pump on the process chamber with the vacuum system at blank-off pressure as oil backstreaming may result. When necessary to shut down the vacuum system for over 8 hours, fill gas ballast with nitrogen for at least 4 hours before stopping.

The right maintenance.

Drain the exhaust oil mist eliminator weekly. If oil is clean, it can be reused by returning to the pump. If it is "milky" or cloudy, it should be decanted before returning to pump reservoir. Cleaning interval is determined by the amounts of particulates accumulated.

Monitor differential pressure across the oil filter. Replace element when filter pressure shows a significant increase above baseline pressure. Actual pressures will be determined by your own process.

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display is the circular PPI, but it would be very simple to reprogram the memory for an offcenter sector sweep or even a bearing/range B-scan.

The circuit (see figure) requires three inputs. The first is a once-per-scan pulse to synchronize the display to the north, the relative heading, or another reference direction. The second is a once-per-degree-of-rotation pulse to advance the sweep rotation. The third input is the normal sweep ramp. The duration of the ramp corresponds to the maximum displayed range. Changing the ramp duration, while holding its peak amplitude constant, changes the maximum displayed range.

There are two main counter sections. The first section, known as the degree counter, counts from 0 to 359 and resets. This counter is also reset by the once-per-scan input pulse to synchronize the counter to the antenna. The counter states are routed in parallel to two ROM's.

The second counter section, known as the quadrant counter, consists of two subsections. One counts from 0 to 89 and resets. It is also reset by both the once-per-scan pulse and the degree-counter reset. The output of this counter is fed to a two-stage binary counter, the 0-to-3 counter, which keeps track of what quadrant the sweep is in.

The absolute values of the sine function normalized to an integer scale of 0 to 255 are stored in the first ROM. The second ROM contains the absolute values of the cosine function normalized to an integer scale of 0 to 255. The ROM data-output lines are connected to programmable attenuators, which are fed by the sweep ramp. The outputs of the programmable attenuators are routed through the quadrant amplifier/switch units. The quadrant switches are formed from 4066 CMOS analog gates and are driven by decoders connected to the quadrant counter. The result is a sweep ramp multiplied by the sine and the cosine of the antenna position.

These two outputs, when fed to the X and Y inputs of an oscilloscope, produce a true PPI display. The 8-bit programmable attenuators, one for the sine and one for the cosine, consist of resistor ladder networks and analog gates. The gates connect the resistors to ground or to the input signal according to the bit pattern from the respective ROM. This circuit has been built and tested and will form the heart of a display system for a bistatic IFF processor at Langley Research Center.

This work was done by John M. Franke and Bradley D. Leighty of **Langley Research Center.** *No further documentation is available. LAR-13328*

Variable Synthetic Capacitance

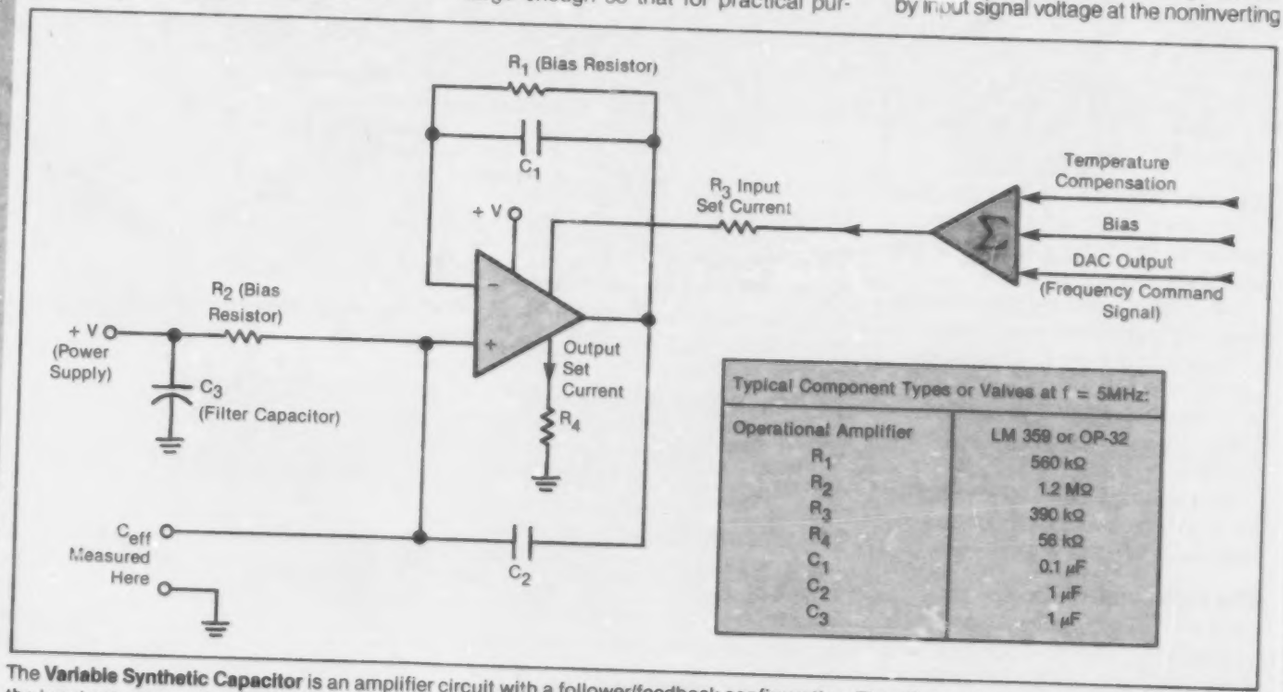
Small oscillator-frequency changes are produced by digital signals.

Goddard Space Flight Center, Greenbelt, Maryland

A feedback amplifier circuit synthesizes an electronically variable capacitance. Because the changes in the effective capacitance are relatively small even with large control-signal voltages, the circuit is insensitive to input noise. The circuit is especially suitable for fine frequency adjustments of piezoelectric-crystal or inductor/capacitor resonant oscillators.

The circuit (see figure) includes an operational amplifier, the gain-bandwidth product of which varies with an input set current, and the output impedance of which varies with an output set current. The inverting input is connected to the output through bias resistor R_1 and parallel bypass capacitor C_1. This capacitor is large enough so that for practical purposes it can be regarded as a short circuit at the intended oscillator frequency. Thus, the signal at the inverting input follows the output signal. Capacitor C_2 is connected in a feedback loop from the output to the inverting input.

In this follower configuration, the voltage gain K_v (output signal voltage divided by input signal voltage at the noninverting



Typical Component Types or Values at f = 5MHz:	
Operational Amplifier	LM 359 or OP-32
R_1	560 kΩ
R_2	1.2 MΩ
R_3	390 kΩ
R_4	56 kΩ
C_1	0.1 μF
C_2	1 μF
C_3	1 μF

The **Variable Synthetic Capacitor** is an amplifier circuit with a follower/feedback configuration. The effective input capacitance depends on the input set current. If the synthetic capacitor is connected across the resonant element of an oscillator, the oscillator frequency can be controlled via the input set current.

input) is given by $K_r = K/(1 + K)$, where K = the open-loop gain of the operational amplifier alone. At a frequency f in the intended operating range of several megahertz to one gigahertz, K can be approximated as $-jf_g/f$, where f_g = the gain-bandwidth product.

These values of K_r and K are used to calculate the circuit input admittance, Y, at the noninverting input. The result is $Y = 2\pi C_2(jf - f_g)/[1 + (f_g/f)^2]$, which is equivalent to the admittance of a large negative resistance in parallel with an effective (synthetic) capacitance of $C_{eff} = C_2/[1 + (f_g/f)^2]$. (The negative resistance can be ignored because it is large in comparison to the resistance with which it is connected in parallel.)

The synthetic capacitance is normally connected across the piezoelectric crystal or other resonant element of an oscillator. The ungrounded side of the element is connected to the noninverting input while the grounded side of the element is connected to the circuit ground. Although C_{eff} and the oscillator frequency, f, depend on each other, the variation in f is so small in practice that C_{eff} and f can both be considered to depend only on f_g.

The input set current is varied to adjust f via its effect on f_g. The input set current is fed through resistor R_3 from a summing circuit. The summing-circuit inputs are a temperature-compensating voltage, a bias voltage, and the output of a digital-to-analog converter (DAC).

The digital input to the DAC is the main frequency-control signal. It can be generated locally or transmitted over a long distance. A typical DAC might have 1,024 steps, with analog output increments of about 5 mV per step. Thus, the oscillator frequency is varied in 512 small steps above and below a central value.

For a 5-MHz crystal oscillator connected to this circuit and using typical component values, each step of the DAC can be made to correspond to a frequency change of 0.005 Hz or even less (≤ 1 part in 10^9). This small change in frequency is achieved with relatively large digital signal voltages so that noise is not a primary consideration. The noise at the DAC output is of the order of nanovolts and thus has no appreciable effect on the frequency.

This work was done by Leonard L. Kleinberg of **Goddard Space Flight Center.** *For further information, Circle 81 on the TSP Request Card. GSC-12961*

High-Resolution Thermal X-Ray Detector

Thermal pulses from single photons can be measured.

Goddard Space Flight Center, Greenbelt, Maryland

A thermal X-ray detector, tested successfully in prototype, in theory can operate as a spectrometer that provides 100 times the spectral resolution of conventional solid-state detectors, with high efficiency from 100 eV to 9 keV. It could be used to detect trace constituents in materials by X-ray fluorescence. It also could be used for measuring the energies of energetic electrons and weak pulses of light.

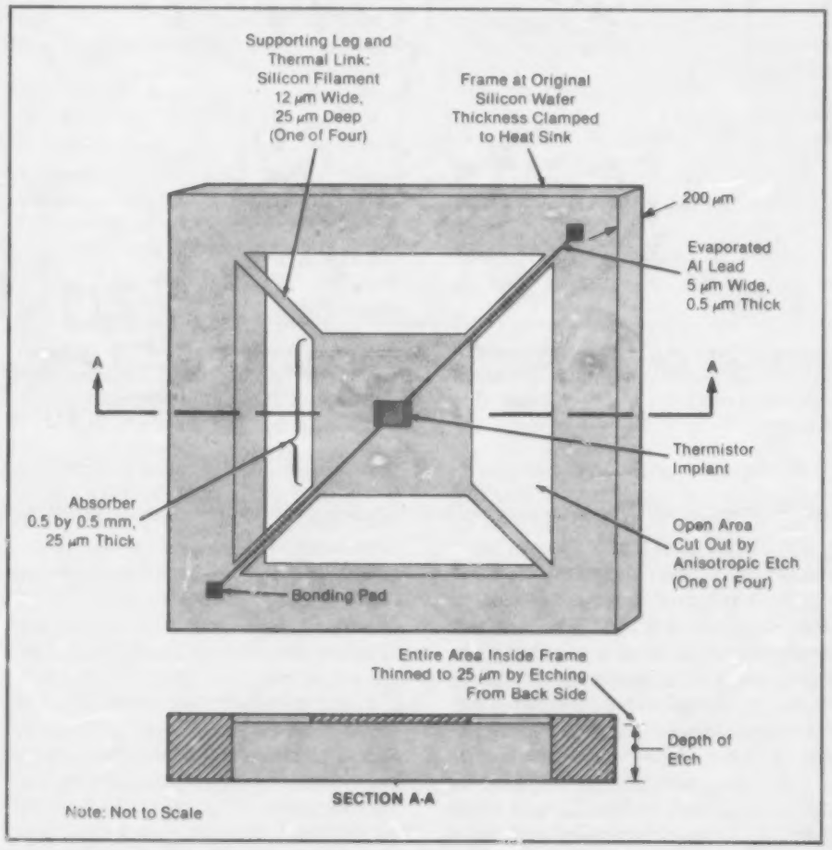
The figure shows a version of the detector, which consists of an X-ray absorber, a temperature sensor in the absorber, and a thermal link from the absorber to a heat sink. An X-ray photon is detected by measuring the temperature rise immediately following the absorption of the photon.

The temperature rise is approximately $\Delta T = U/C$, where U is the X-ray energy and C is the detector heat capacity. If the thermal conductance of the thermal link equals G, then the detector element decays back toward the heat-sink temperature exponentially with a time constant $\tau = C/G$.

In a practical detector, the time constant of the output pulse is changed by electrothermal feedback from τ to an effective time constant τ_e. Therefore in the time domain an impulse of absorbed energy U at time $t = 0$ produces a decaying exponential pulse of voltage

$$V(t) = (US(0)/\tau_e)\exp(-t/\tau_e)$$

where S(0) is the detector responsitivity at zero frequency (measured in V/W). The utility of this device as a detector depends on the ability to measure this pulse height accurately.


Supporting Leg and Thermal Link: Silicon Filament 12 μm Wide, 25 μm Deep (One of Four)
Frame at Original Silicon Wafer Thickness Clamped to Heat Sink
200 μm
Evaporated Al Lead 5 μm Wide, 0.5 μm Thick
A
A
Thermistor Implant
Absorber 0.5 by 0.5 mm, 25 μm Thick
Open Area Cut Out by Anisotropic Etch (One of Four)
Bonding Pad
Entire Area Inside Frame Thinned to 25 μm by Etching From Back Side
Depth of Etch
SECTION A-A
Note: Not to Scale

The Thermal X-Ray Detector is made on a silicon wafer as an integrated circuit. The temperature sensor is implanted in the square absorber in the middle.

The fundamental limit to the sensitivity of such a device is imposed by the thermodynamic temperature fluctuations of

the sensor. The rms temperature fluctuations can be written as

$$\Delta T_{rms} = (k_B/C)^{1/2}T$$

so that $\Delta U_{rms} = (k_B C)^{1/2}T$, where k_B is Boltzman's constant. With a proper choice of materials, adequate X-ray absorption out to energies of 9 keV can be achieved while maintaining sufficiently low heat capacity to offer good spectral resolution ($\Delta U \leq 5$ eV full width at half maximum). To achieve the excellent resolution offered by this technique, the devices must be cooled to less than 0.3 K.

The device shown in the figure includes a silicon photon-absorbing element, a semiconductor on the insulating side of the metal/insulator transition to sense the absorber temperatures, and etched silicon filaments at the corners as the thermal link from the absorber to the heat sink. Many alternative designs are possible.

In laboratory tests, devices of this type exhibited a resolution of 130 eV full width at half maximum at 6 keV photon energy. This is better than the 155 eV, which is the best achieved using solid-state detectors at this energy. These results were obtained with a detector of relatively high heat capacity operating at 0.3 K and are in good agreement with theory: The implication is that devices of lower heat capacity operating at 0.1 K will come near the theoretical predictions.

This work was done by S. Harvey Moseley of **Goddard Space Flight Center.** *For further information, Circle 31 on the TSP Request Card.*
GSC-12953

Two-Element Transducer for Ultrasound

The separation of transmitting and receiving units improves the probing of deep tissue.

NASA's Jet Propulsion Laboratory, Pasadena, California

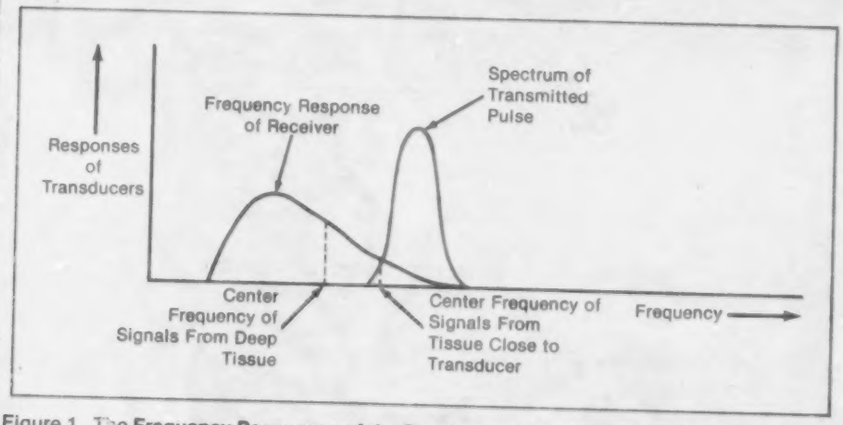

Responses of Transducers
Frequency Response of Receiver
Spectrum of Transmitted Pulse
Center Frequency of Signals From Deep Tissue
Center Frequency of Signals From Tissue Close to Transducer
Frequency

Figure 1. The **Frequency Responses of the Receiver and Transmitter Would Be Different** in a new dual-element ultrasonic transducer. The receiver would peak at lower frequencies more characteristic of the spectrum of the ultrasound pulse after passage through tissue.

A proposed ultrasonic transducer would have dual elements to increase the depth at which sonic images can be made of biological tissue. Present transducers use the same elements for transmitting and receiving ultrasonic signals. The proposed transducer would use separate transmitting and receiving elements, and the frequency response of the receiving element would be independently designed to accommodate the attenuation of higher frequencies by the tissue.

The new transducer is intended for pulse-echo ultrasonic systems, in which reflected sound pulses reveal features in tissue.

Soft tissue attenuates sound at a rate of about 1 decibel per megahertz per centimeter of round-trip path length. Thus, the higher frequencies in a pulse are attenuated more as the pulse penetrates tissue, and the center frequency in a received pulse may be significantly lower than in the transmitted pulse. The new center frequency may not correspond to the most sensitive receiving region of the transmitter/receiver. The received signal will thus seem weak, and details of the reflecting features will be lost.

In the proposed dual transducer, the receiver characteristics would not have to be as much of a compromise with the required transmitter characteristics. The receiver would be designed to be most sensitive to the expected range of echo-pulse center frequencies (see Figure 1). The transducers could be concentric; for example, a circular concave piezoelectric element encircled by an annular concave piezoelectric element (see Figure 2).

This work was done by Dennis H. Le Croissette and Richard C. Heyser of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 43 on the TSP Request Card.*
NPO-16591

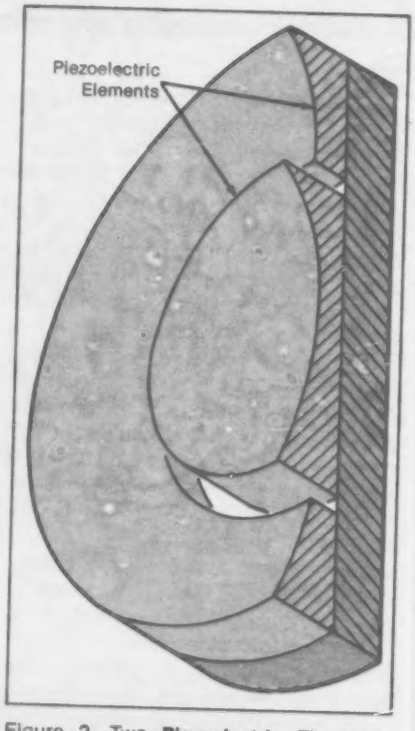


Figure 2. The **Piezoelectric Elements,** shown here in a cutaway view, would be the transducers in an ultrasound transmitter/receiver.

Temperature-Sensitive Oscillator

An ingestible thermometer consists of an oscillator with temperature-dependent frequency.

Goddard Space Flight Center, Greenbelt, Maryland

A new, small, inexpensive, low-power, temperature-sensing circuit is suitable for use as an ingestible thermometer for measuring internal body temperature. The device is a quartz-crystal oscillator, the frequency of which changes in proportion to the change in temperature.

The circuit does not depend on any temperature sensitivity of the crystal itself. Thus, readily-available, inexpensive, crystals can be used. Previous crystal-oscillator temperature-sensing circuits required expensive crystals which had to be specially cut to provide large, linear temperature coefficients. The new circuit also avoids the linearity and stability problems of thermistor-based temperature-sensing circuits.

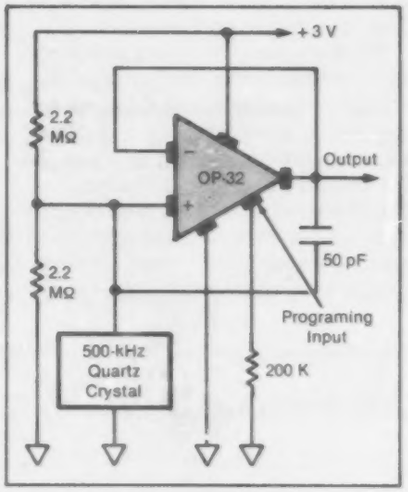
The circuit includes an operational amplifier, the gain-bandwith product of which can be varied by varying the bias current at the programing input. Because of the temperature variation of a forward voltage drop across two internal diodes, the bias current (through resistor R_3) varies with temperature, thereby varying the gain-bandwidth product. The value of R_3 is selected to set the bias and gain-bandwidth product to the desired values at a given temperature (for example, normal body temperature).

The oscillator operates in the rolloff region of the gain-versus-frequency characteristic of the amplifier. With the capacitor connected between the output and the non-inverting input, the effective capacitance across the crystal changes with the gain-bandwidth product and therefore with temperature. This, in turn, changes the crystal resonant frequency slightly.

The oscillator (see figure) operates at about 500 kHz, a frequency that is readily transmitted through the body and for which miniature crystals are available. Using the component values shown, the capacitance varies with temperature in such a way that the oscillator frequency increases linearly over the temperature range of 30° to 40°C, at about 4 Hz per °C. In general, achieving linearity depends on selecting an operational amplifier with a sufficient change in gain-bandwidth product for a given set current and a crystal with large enough motional capacitance to allow it to be pulled over a relatively large frequency range with a relatively small capacitance change.

This work was done by Leonard L. Kleinberg of **Goddard Space Flight Center.** *For further information, Circle 105 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center [see page 29]. Refer to GSC-12958.



A Temperature-Sensitive Oscillator with a nearly linear temperature coefficient of frequency can be obtained by using a high-speed, high-gain, programable operational amplifier such as the OP-32 to produce a temperature-varying reflected capacitance across a quartz crystal.

Multikilowatt Bipolar Nickel/Hydrogen Battery

High energy densities appear feasible.

Lewis Research Center, Cleveland, Ohio

A nickel/hydrogen battery utilizing a bipolar construction in a common pressure vessel, which addresses the needs for multikilowatt storage for low-Earth-orbit applications, has been designed and a 10-cell prototype model tested. The modular-concept-design 35-kW battery projected energy densities of 20 to 24 Wh/lb (160 to 190 kJ/kg) and 700 to 900 Wh/ft^3 (90 to 110 MJ/m^3) and incorporated significant improvements over state-of-the-art storage systems.

Results of low-Earth-orbit multikilowatt-mission studies have indicated a need for electrochemical storage subsystems that will be quite different from those in current use. The general trend for the multikilowatt application is toward higher cell capacity and higher battery voltage. It is generally conceded that the nickel/hydrogen system would represent the best candidate for scaleup from its current size of from 30 to 50 Ah to a size more compatible with the multikilowatt missions.

An advanced configuration for the nickel/hydrogen system that fulfills the requirements of future multikilowatt low-Earth-orbit missions was designed. The result was a complete battery system that incorporated active cooling for thermal control, an improved oxygen-recombination method, and pore-size engineering to facilitate electrolyte management. The individual cells are constructed in a bipolar manner and are contained within a common pressure vessel. The cell stack resembles that of a fuel cell where only one electrode pair is housed in each cell compartment. Thus, the electrode/battery ampere-hour capacity is a function of the electrode dimensions.

Active cooling is accomplished by a liquid coolant or other suitable means. The battery power output was designed to

supply 35 kW for a 35-min eclipse. This was accomplished with a 130-Ah, 275-V battery supplying 130 A. The high-voltage/low-current combination minimizes distribution losses and the weight of terminals, connectors, and current-carrying conductors — a major consideration for high-power systems. The high-voltage/low-current system is ideal for a bipolar design since the total cell capacity is in a single electrode plate, and current densities must be kept within reasonable limits for optimum performance.

There are some surprising and significant results of this design regarding energy densities and projected cost. The gravimetric energy density of this nonweight-optimized design is about 20 Wh/lb (160 kJ/kg), a 40 to 50-percent increase over a battery comprised of state-of-the-art individual-pressure-vessel (IPV) nickel/hydrogen cells. Similarly, the volumetric energy density is about 1 kWh/ ft^3 (130 MJ/m^3), a threefold to fourfold improvement over an IPV battery.

The bipolar design is especially attractive when looking at cost and system integration. With the bipolar design, there is only one stack and vessel; whereas about 450 state-of-the-art IPV cells are needed in series/parallel combination to match the 35-kW power requirements.

Two 10-cell, 6.5-Ah batteries based on the design were fabricated and tested. The test results of these first bipolar batteries are very encouraging. A total of 4,000 cycles at 80-percent depth-of-discharge has been obtained. A cycle-life goal of 30,000 cycles at lesser depth-of-discharge (50 percent) appears achievable with minor design changes.

The discharge-rate capability of this design exceeds 20 C. At the 10-C discharge rate, 80 percent of the battery capacity can be withdrawn in 6 min. Low-polarization voltages that result in cyclic watt-hour efficiency of 75 to 80 percent have been demonstrated. This demonstration indicates that a high-voltage bipolar battery within a common pressure vessel makes an ideal building block for such large, advanced energy-storage systems as the space station.

This work was done by the Electrochemistry Branch of **Lewis Research Center.** *Further information may be found in NASA TM-82844 [N82-24647/NSP], "Design of a 35 kilowatt Bipolar Nickel-Hydrogen Battery for Low Earth Orbit Applications."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14244

Unbalanced-to-Balanced Video Interface

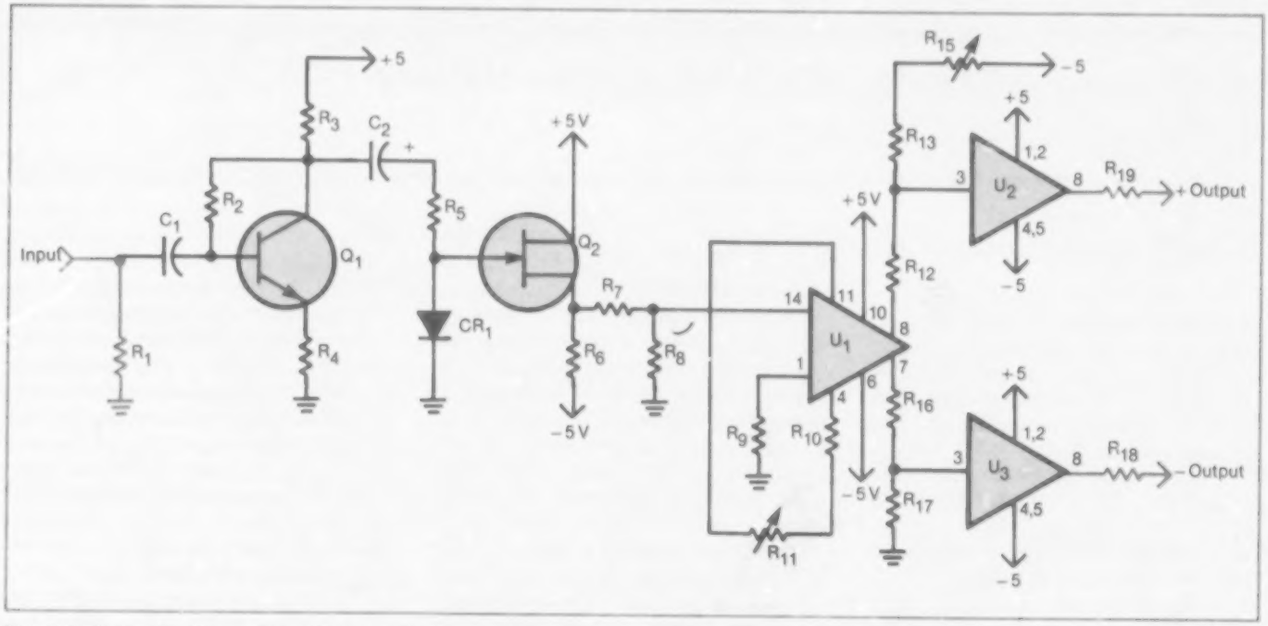
Equal but opposite video waveforms are generated.

Lyndon B. Johnson Space Center, Houston, Texas

An interface circuit for video signals converts a 75-ohm unbalanced input to a 75-ohm balanced output. The circuit (see figure) is intended for use with an input television signal having polarity, amplitude, and dc bias such that the tips of the synchronizing pulses lie at zero volts while the reference white level is a specified positive dc level (typically about 1 volt).

The unbalanced input line is terminated in a 75-ohm resistor, R_1. Capacitor C_1 blocks the dc component of the input so that only the time-varying component is fed to Q_1 and is inverted in polarity.

The combination of capacitor C_2, resistor R_5, and diode CR_1 acts as a dc restorer for the inverted waveform. Since the tips of the synchronizing pulses are at the positive extremity of the inverted waveform, the diode clamps them near zero volts, while allowing the negative-polarity remainder of the signal to be fed to buffer amplifier Q_2. The input impedance of Q_2 is high enough to prevent the loss of dc restoration during



This **Interface Circuit** converts a 75-ohm unbalanced video input to a 75-ohm balanced output.

the horizontal-line picture-transmission time between synchronizing pulses.

Integrated circuit U_1 takes the unbalanced output of Q_2 and produces a balanced output to drive integrated-circuit current amplifiers U_2 and U_3. R_{11} is used to adjust the output-signal amplitude. R_{15} is a fine-adjustment control to set the synchronizing-pulse tips to zero output voltage. R_{13} and R_{19} match the amplifier outputs to the two conductors of the balanced 75-ohm output transmission line. Thus, the output-line conductors carry opposite-polarity replicas of the input video signal.

This work was done by James E. Richardson of Taft Broadcasting Corp. for **Johnson Space Center.** *For further information, Circle 108 on the TSP Request Card.* *MSC-20950*

Passive Element Shapes Antenna Radiation Pattern

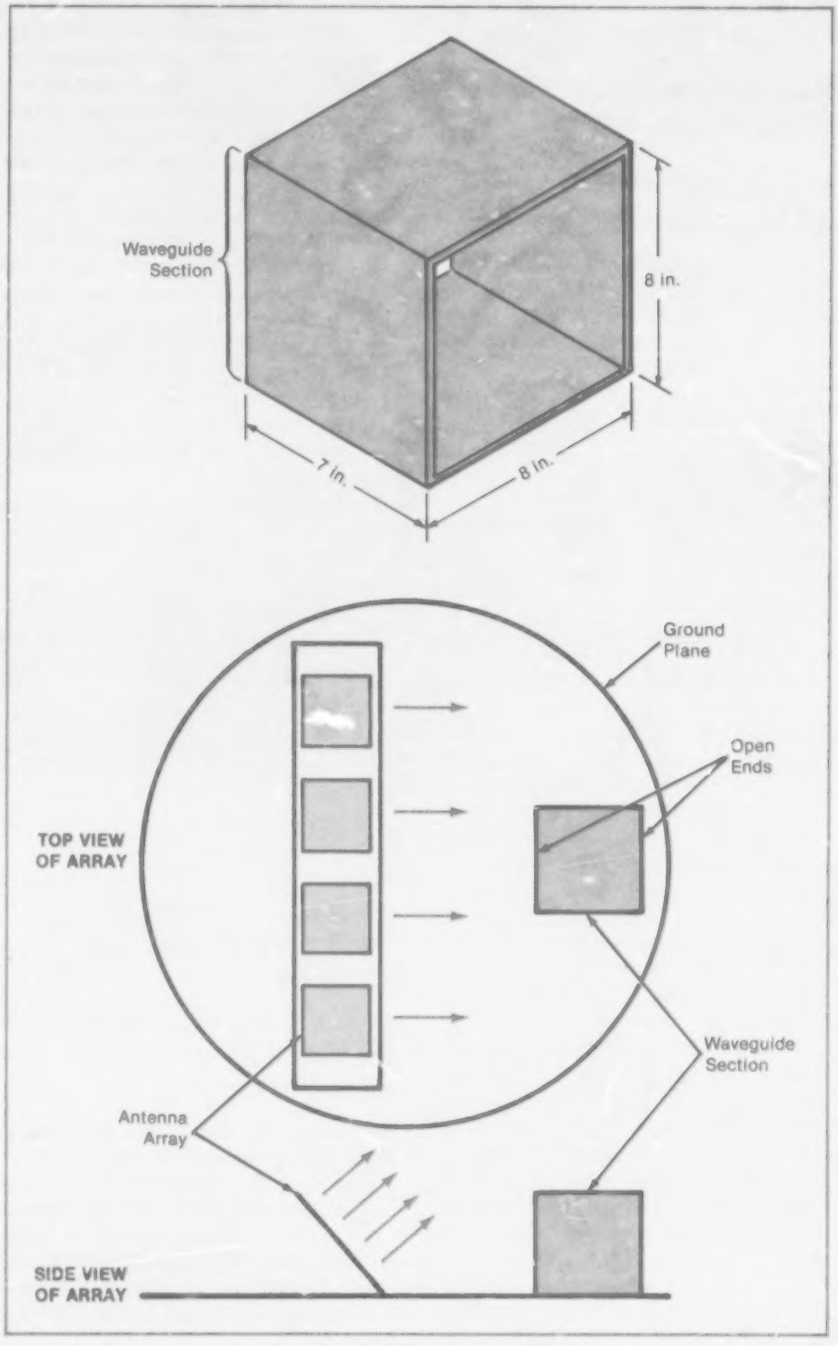
A parasitic waveguide element suppresses ground-reflected multipath radiation.

NASA's Jet Propulsion Laboratory, Pasadena, California

A small section of waveguide placed in front of a phased-array antenna operating at 850 MHz (see figure) modifies the radiation field by reducing power density parallel to and below the ground plane without significantly affecting the primary radiation at angles greater than 20° above the horizontal. The waveguide acts as a parasitic radiator that shifts the phase of a portion of the wavefront by approximately 180°, causing partial cancellation in the ground plane, thereby reducing the radiation intensity in that direction by about 10 dB. This produces a corresponding reduction in multipath radiation scattered from the ground.

This waveguide technique could also be used to decouple two nearby antennas. A piece of waveguide would be positioned to create a null in the pattern of one of the antennas in the direction of the other antenna. The technique could be used at both antennas if necessary.

The waveguide dimensions are chosen so that the phase velocity in the waveguide is twice that in free space at the operating wavelength. The waveguide works with circularly and linearly polarized radiations. In contrast with such other ground-plane radiation-suppression devices or techniques as varying the shape or length of a ground plane, inductive gratings, or absorbers, the waveguide takes up less room. Also, in contrast with other techniques, the waveguide allows the radiation to retain a more nearly circular polarization down to and below the ground plane. The new technique is also quite economical, since the short length of waveguide required is relatively inexpensive.



A **Passive Waveguide Element** modifies the radiation pattern of a phased-array antenna. In the case shown, the goal is to reduce the radiation along and toward the ground.

When the technique was tested in the 850-MHz system, the length and the placement of the waveguide element were determined empirically. A 7-in. (17.8-cm) long, 8-in. (20.3-cm) square waveguide proved to be optimum.

This work done by Mark E. Bonebright and Derling Killion of Cubic Corp. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 107 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office — JPL [see page 29]. Refer to NPO-16632.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Reliability Research for Photovoltaic Modules

Problems of reliability analysis are described.

A report describes the research approach used to improve the reliability of photovoltaic modules. The research is aimed at raising the useful module lifetime to 20 to 30 years.

The first research task is to identify the principal degradation mechanisms. This requires the documentation of failures in service and in laboratory accelerated-aging tests. Thus far, experience has shown that increased temperature is the most reliable aging accelerator.

The next task is to establish reliability goals specific to each degradation mechanism. This requires quantification of the economic importance, at the system level, of each failure or instance of degradation. Included in this analysis are the power loss due to encapsulant soiling, open- or short-circuit failures of individual cells, statistical and economic properties of circuit redundancy, and the effects of these and other features on the life-cycle cost per unit of energy. For example, one analysis of 13 failure mechanisms in a module with a 30-year design life chose component reliability goals such that the cost of energy would be 20 percent higher than it would be if the system were to have no failures.

To achieve the quantitative reliability goals, it is necessary to measure the dependencies of the degradation or failure rates on the parameters of operating stresses, component designs, and manufacturing processes. This is a complicated problem requiring detailed physical and chemical studies and statistical analyses of failure-test data.

Degradation prediction involves the application of the parametric dependencies to mathematical models of the time histories of applied stresses. For example, a simplified characterization of the daily thermal cycling coupled with a knowledge of the thermal-expansion and fatigue characteristics of a module would enable a prediction of the time to fatigue failure of one of the metal interconnections or a calculation of the accelerating factor of a thermal-cycling test.

The development of cost-effective solutions to the module-lifetime problem requires compromises between degradation rates, failure rates, and lifetimes, on one hand, and the costs of initial manufacture, maintenance, and lost energy, on the other hand. Life-cycle costing integrates the disparate economic terms, allowing cost effectiveness to be quantified, thereby allowing the comparison of different design alternatives. The system design may evolve somewhat from the original concept as the designer iteratively focuses in on the cost-optimum solution. An important consideration is to minimize the sensitivity of the system life and cost to processing variations and design uncertainties.

The last step in the reliability program is extensive testing of the product. By the end of the program, data with quantitative correlations to field applications should be available. The testing must be realistic, including likely interactions with users' equipment under adverse field conditions.

This work was done by Ronald G. Ross, Jr., of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Reliability Research Toward 30-Year-Life Photovoltaic Modules," Circle 103 on the TSP Request Card.*
NPO-16595

Guidelines for SEU-Resistant Integrated Circuits

Designs are examined that immunize chips to single-event upsets.

A paper presents recent results of a continuing program for increasing the resistance of integrated circuits to single-event upset (SEU). The results are based on a study of test data for heavy-ion SEU in more than 180 different types of devices. (Some of the devices perform identical functions but are made by different processes.)

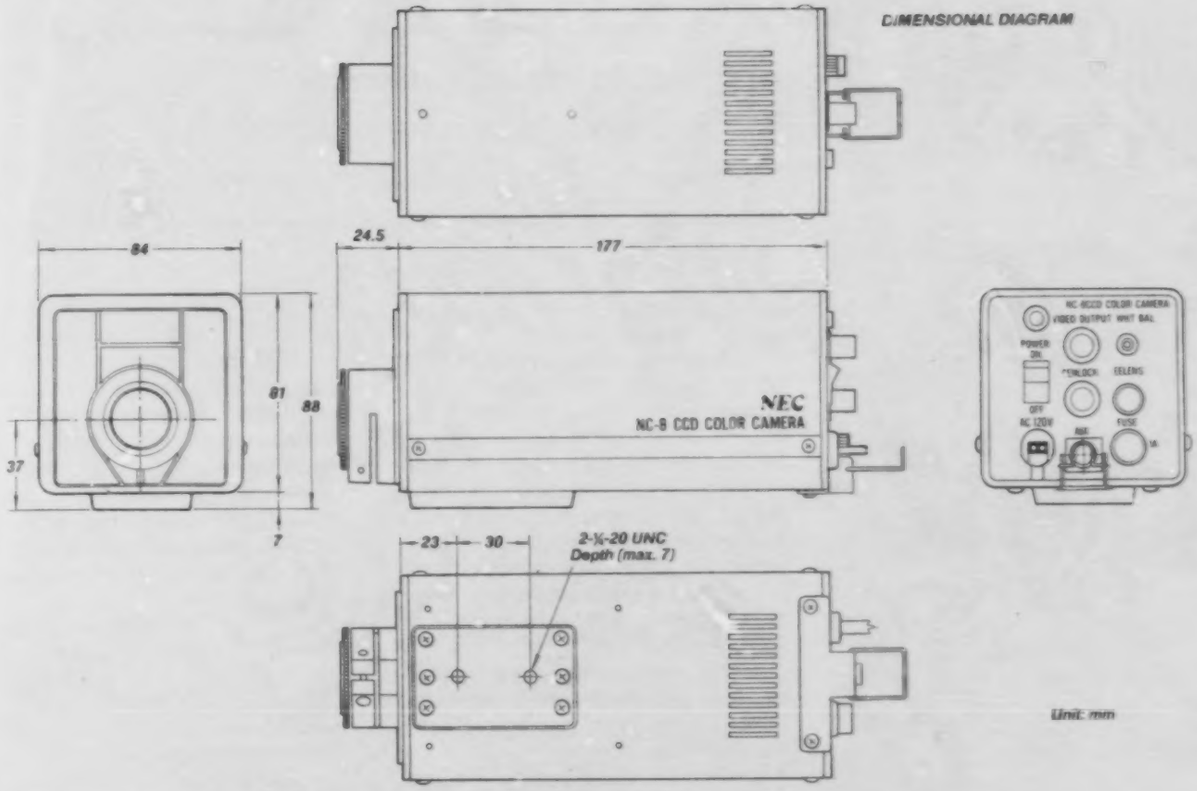
A single-event upset — an error caused by a single atomic particle interacting with an integrated circuit chip — is usually "soft"; that is, it can be corrected by subsequent electrical input. Soft errors occur in random-access memories, microprocessors, programmable read-only memories, and logic devices. They are less likely to occur in logic circuits but are more difficult to detect and correct there. SEU has been a problem primarily in integrated circuits in space vehicles. However, terrestrial cosmic rays, which contain trace quantities of protons and neutrons, pose a threat to very-large-scale integrated chips as their circuit features approach submicron dimensions.

The program is examining the test data to extract generalizations about the SEU resistance of parts in terms of fabrication technology. The report notes that certain conclusions can already be drawn. For example, a broad ranking of SEU resistance, or "hardness," would place complementary metal-oxide-semiconductor/silicon-on-sapphire (CMOS/SOS) devices at the top of the list. Following in order of decreasing hardness would be CMOS on bulk silicon chips, n-channel MOS (NMOS), p-channel MOS (PMOS) and bipolar devices, and dynamic NMOS devices.

The susceptibility to upset increases with decreasing feature size, and this effect is more dominant than the differences in technology. Newer versions of a given device are more susceptible to SEU than their larger feature size predecessors. Faster parts are more susceptible than slower parts. However, individual device variability is great so that predictions cannot substitute for tests.

The program is also examining developments in mathematical models for SEU. Mathematical models can be used to a certain extent in designing devices resistant to SEU, but actually making such devices requires close collaboration between an experienced modeler and a fabrication group with expertise in various manufacturing processes, devices, and circuit design.

This work was done by Donald K. Nichols of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the paper, "Guidelines for Designing Parts Resistant to Single Event Upset," Circle 109 on the TSP Request Card.*
NPO-16596



OUR DESIGN FITS YOUR SPECS.

NEC invites you to take a look inside the NC-8 single chip color camera — the camera designed with your specifications in mind. With the lightweight, flexible NC-8, you get high definition and resolution, very low lag and no burn in. It resists shocks, is immune to magnetic distortion, and because its pixels are arranged in a high precision matrix, there is no geometric distortion. It includes Gen Lock as a standard feature. It is equipped for any C-mount lens including auto iris.

This durable little camera is a match for any of your toughest video camera requirements and is easily adaptable to a wide variety of settings.

NEC, the world's largest manufacturer of semiconductors, offers an entire line of solid state industrial cameras—all high quality, hard-working products from a respected source.

C&C
COMPUTERS AND COMMUNICATIONS

Specifications

Pickup	Interline transfer type CCD x1
Number of picture element	H427xV492
S/N ratio	47dB (illuminance channel, standard recording conditions, AGC: off)
Resolution	Horizontal: 280 lines Vertical: 350 lines
Sensitivity Minimum illumination	1,600 Lux F4.0 10 Lux F1.4 AGC: ON (20% signal output level)
White balance adjustment	Manual/Remote
Lens mount	C-Mount
Power consumption	Approx. 6.5W (less than 9VA)
Weight	Approx. 1.4kg [3.1 lbs] (excluding lens)

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For more information about the NC-8, TI-22AII, TI-22PII and TI-26A industrial cameras, contact the Industrial Video Group, Broadcast Equipment Division, NEC America, Inc., 130 Martin Lane, Elk Grove Village, IL 60007. Toll free 1-800-323-6656. In Illinois phone 312/640-3792.

Circle Reader Action No. 369

Electronic Systems

Hardware, Techniques, and Processes

44 **Adjustable Work Station for Video Displays and Keyboards**
46 **Analog Video Image-Enhancing Device**
48 **Automated Signal-to-Noise Ratio Measurement**
49 **Phase-Measuring System**
49 **Wireless "Jump" Starts for Partly Disabled Equipment**

Books & Reports

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Computer Programs

74 **Economic-Analysis Program for a Communication System**

Adjustable Work Station for Video Displays and Keyboards

The station is adaptable to operator's comfort.

Marshall Space Flight Center, Alabama

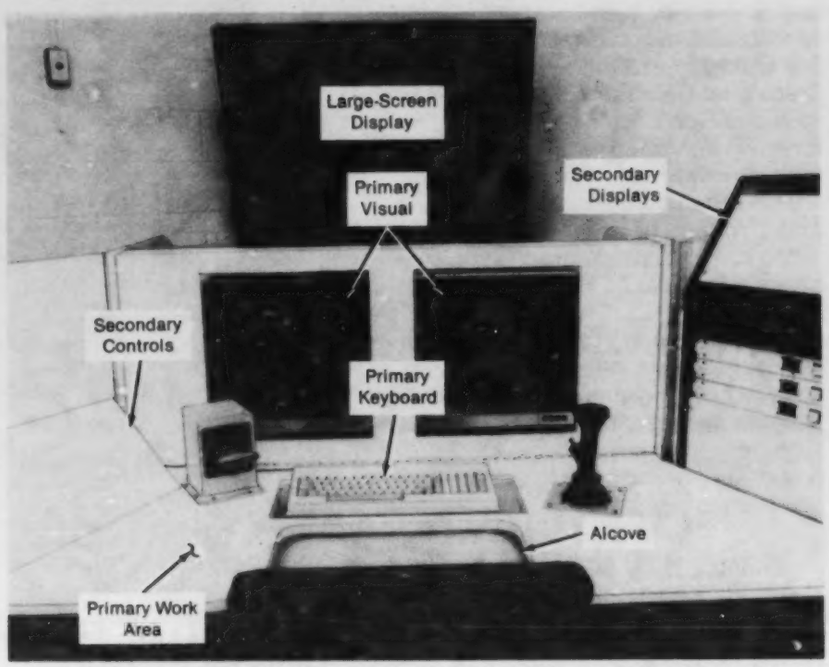
A work station for video displays and keyboards is adaptable to the operational and anthropometric requirements of individual operators. Visual displays can be placed beyond the keyboard and in line with the inclination of the keyboard to minimize the operator's head movement. In addition, the station is arranged so that the operator's eyes and hands are focused onto three primary control and display areas. This quickens operating response and decreases the chance of error, since the input devices and feedback to the operator are collocated.

The figure shows the work station and the three primary and three secondary work surfaces. A brief description of each feature follows:

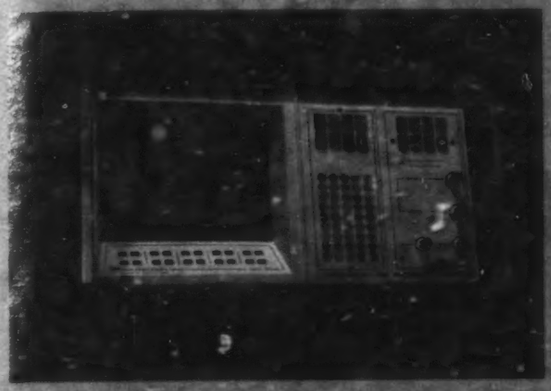
- The primary visual panel accommodates two video-display units of up to 19 in. (47.5 cm) diagonal and their associated controls.
- The primary keyboard panel is designed for a wide range of keyboard configurations. The panel is rotatable through a 30° arc.
- The primary work panel is a desk top with an alcove in front of the keyboard. The panel, which can be outfitted for hand controls, can be adjusted to tilt down, away from the operator, allowing the full support of the arms during hand movements.
- The secondary control panels are slanted wings attached to the primary work table. These wings can be removed independently to permit reconfiguration.
- The secondary display panels are located on two vertical side wings. They form an environmental enclosure and allow the mounting of infrequently used displays.
- The large-screen display is a 3- by 4-ft (0.9- by 1.2-m) television projection display mounted in front of the workstation. This display, showing either of the two primary visual monitors or a third independent display, can be viewed by other people without disturbing the operator.

This work was done by Fred Roe of **Marshall Space Flight Center** *and by Nicholas Shields, Jr., Mary Frances Fagg, and David Henderson of Essex Corp. For further information, Circle 36 on the TSP Request Card.*

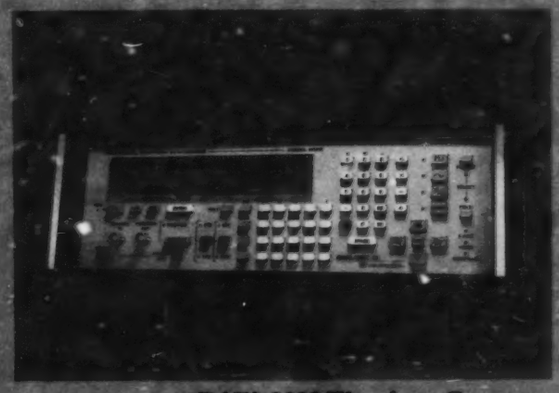
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-26009.



The **Work Station** includes an adjustable work surface and equipment that can be tilted to suit the operator. The equipment is placed to minimize operator fatigue and errors.



DATA 6000 Waveform Analyzer



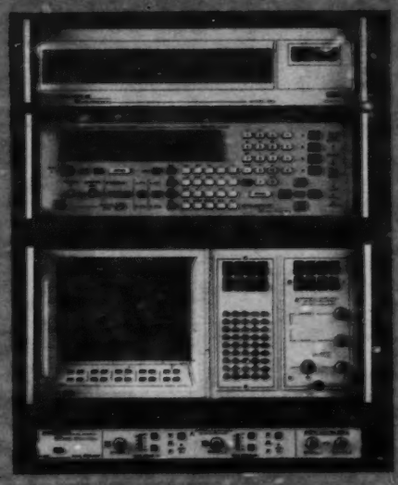
DATA 2020 Waveform Generator

Rule the Waves

Coming...

The DATA 6000 Universal Waveform Analyzer offers the ultimate in signal acquisition and on-board waveform analysis in one unit—without programming. Front panel commands are available for complex waveform operations, such as FFT and Correlation as well as scalar parameters such as Max., Min., Width, Rise, or PK-PK, using the display cursor and crosshair. For specialized measurements, the 6000 can also store analytical routines internally.

- Digitizing Plug-Ins from millihertz to 100MHz sample rates.
- An ultra-high dynamic range digitizing plug-in: 1MHz at 16 bits.
- Simultaneous multi-channel sampling with pre- and post-trigger transient capture.
- FFT (Magnitude and Phase), Convolution, Correlation, Waveform Average, Amplitude Histogram, etc.
- Direct plotter drive for HP-GL compatible plotters.
- Companion Model 681 Flexible Disk Drive for waveform and program storage.
- Full Programmability for ATE via IEEE-488 or RS-232 interface.



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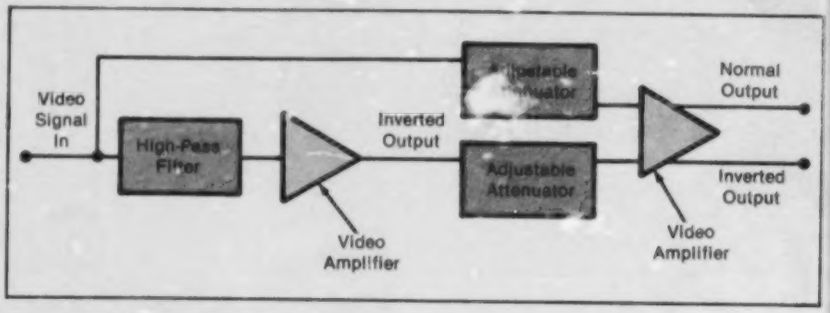
For additional information Circle RAC No. 452
For a demonstration Circle RAC No. 453

Analog Video Image-Enhancing Device

This inexpensive system also yields a pseudo-three-dimensional effect.

Langley Research Center, Hampton, Virginia



This Analog Video Device is added to a video monitor for image enhancement. The circuit is inexpensive, easy to use, and can be adapted to many closed-circuit video systems.

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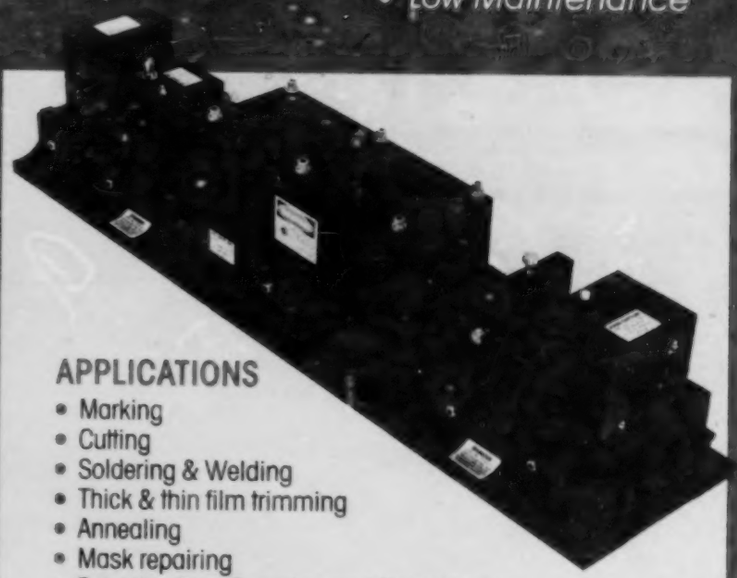

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An analog video image-enhancing device improves the appearance of technical photographs by selectively compressing their overall dynamic ranges while accentuating edges or small details of greatest interest. Analog video circuitry is used to provide an inexpensive real-time image processing technique.

The system includes a video camera with a lens, connected to a video monitor. A circuit (see figure) is added to the monitor for analog video enhancement. The video signal is obtained from the monitor at a point beyond where the synchronization signals are detected, thus eliminating the need to regenerate a composite video signal.

The signal is high-pass filtered with an adjustable resistor/capacitor filter. The high-pass signal is then amplified with an adjustable-gain video amplifier. The unfiltered signal is also adjustable from a gain of near zero to about two. The two signals are added in a second video amplifier, and the sum is sent back to the monitor. Black-and-white reversal is possible in the second amplifier, allowing negatives as well as prints to be examined directly, as indicated in the figure.

Adjustments of the new image parameters along with the conventional variability of monitor brightness and contrast enable the control of a wide range of image enhancement. In addition, the time constant on the high-pass filter results in a pseudo-three-dimensional effect, which, in some cases, shows detail more clearly.

This work was done by Leonard M. Weinstein of **Langley Research Center.** *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center, [see page 29]. Refer to LAR-13336.

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Circle Reader Action No. 373

Automated Signal-to-Noise Ratio Measurement

Computer-controlled spectrum analysis gives rapid results for communication systems.

Lyndon B. Johnson Space Center, Houston, Texas

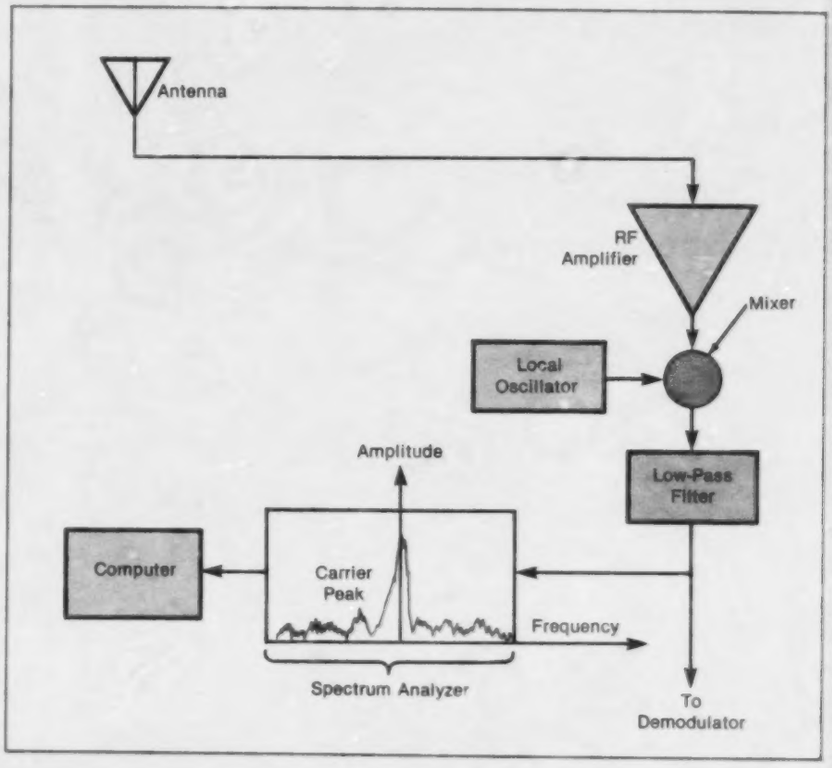
Based on spectrum analysis, an automated procedure for measuring the signal-to-noise ratio (S/N) in a radio-frequency (RF) signal has several advantages over the customary manual method:

- Measurements can be made quickly, without physical disruption of the communication link.
- The dynamic range is greater than with the power-meter method, making it possible to examine weak signals.
- The signal and noise can be differentiated without the adjustment of a variable attenuator, which cannot always be used when a signal is received from a remote transmitter.
- No external bandpass filter is required to find the S/N spectral density ratio.
- The old signal-on/signal-off technique requires the assumption that the system is linear, which is rarely the case. The new method requires no such assumption and provides more-accurate measurements because there is always a signal in the channel.

The new method was developed to obtain accurate and rapid measurements of the S/N ratio in digitally modulated signals transmitted from remote stations. The ratio is used to plot the received bit-error rate. This plot can be compared to a "best possible" curve to see how well a communication system is performing. The measurement of S/N is also needed to assess the radiated power, signal quality, and signal-tracking threshold.

As illustrated schematically in the figure, a spectrum analyzer is used to make several (e.g., 10) noise-amplitude measurements uniformly distributed in a pass band selected by the user and centered on the receiver intermediate frequency. The numerical average of these measurements is deemed to be the noise.

The spectrum analyzer finds the signal peak through its ability to find the strongest signal in a specified bandwidth. The search algorithm is performed four times, with a gradually-narrowing search bandwidth, the final search bandwidth, being a few hundred Hertz. The amplitude of this peak is measured and deemed to be the amplitude of the desired signal.



A Computer-Controlled Spectrum Analyzer locates the carrier signal in the intermediate-frequency band and measures both the carrier amplitude and the amplitude of noise in several channels near the carrier frequency. The computer then computes the ratio of the signal to the average noise. Because the measurements and calculations are rapid, this system can be used in fading communication channels.

The corresponding S/N is then calculated by division of the measured signal by the measured noise. The algorithm used in the measurements and calculations is programmed into a microcomputer. The control of the spectrum analyzer is given to the computer, which can repeat the process for many data points, depending upon the type of communications-performance testing taking place.

This method of determining S/N cannot be applied to a modulated carrier signal; modulation suppresses the carrier and produces sidebands that look like noise to the spectrum analyzer. Nevertheless, the high speed of the automated S/N-measurement process permits it to be carried out during brief periods when modulation is off. Hence, this method does not interfere appreciably with normal transmissions and does not incur a large delay that would cause a lack of correspondence between the bit-error rate and the S/N.

This work was done by Joseph E. Pineda of Lockheed Engineering and Management Services Co., Inc., for **Johnson Space Center.** *For further information, Circle 59 on the TSP Request Card.* *MSC-21021*

Phase-Measuring System

The phase difference between a signal and its harmonic is displayed directly.

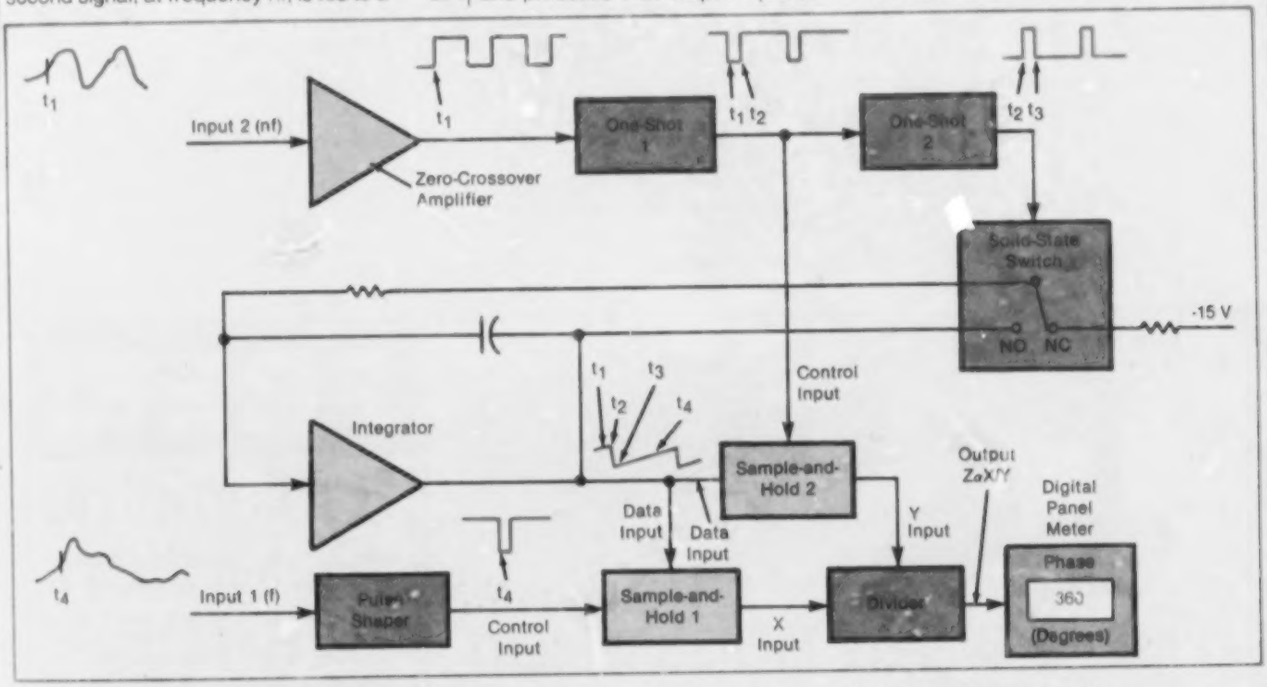
Langley Research Center, Hampton, Virginia

A system developed and in use at Langley Research Center measures the phase between two signals of the same frequency or between two signals, one of which is the harmonic multiple of the other. This simple and inexpensive device combines digital and analog components to give accurate phase measurements.

As shown in the figure, one signal at frequency f is fed to a pulse shaper, which produces a negative pulse at time t_4. This pulse is applied to the control input of sample-and-hold module 1. The second signal, at frequency nf, is fed to a zero-crossover amplifier, which produces a square wave at time t_1. This signal drives the first one-shot, which produces a narrow negative pulse at t_1. This signal then drives a second one-shot, which produces a narrow positive pulse at time t_2. This pulse is used to turn on a solid-state switch and reset an integrator circuit to zero.

The output of the integrator is fed to the data inputs of the two sample-and-hold-modules. Sample-and-hold module 2 receives its control pulse from one-shot 1 at t_1 and produces a dc output equal to the maximum output of the integrator. This signal is fed to the Y input of the divider module. The output of sample-and-hold module 1 is a dc voltage equal to the integrator output level at time t_4; this voltage is fed to the X input of the divider. The output of the divider is a dc voltage proportional to X/Y and to the phase angle between the two input signals. The dc voltage is fed to a digital panel meter which, with proper scaling, displays the phase angle directly.

This work was done by William T. Davis of **Langley Research Center.** *No further documentation is available.*
LAR-13439



The **Digital Panel Meter** displays the difference in phase between harmonically related inputs 1 and 2.

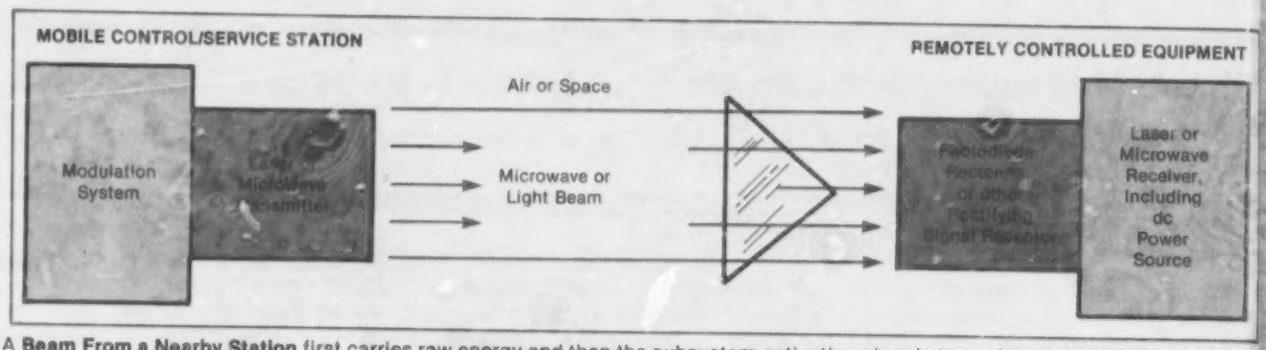
Wireless "Jump" Starts for Partly Disabled Equipment

Equipment might be activated when normal remote starting does not work.

Lyndon B. Johnson Space Center, Houston, Texas

A scheme for activating a satellite crippled by discharged storage batteries would allow the Space Shuttle crew to turn on the satellite even though it does not respond to the normal initiation signals from Earth. The scheme would make extravehicular activity by the crew unnecessary for starting the satellite. Potential terrestrial applications for the scheme could include the starting of robots on such remotely-controlled hazardous tasks as the handling of explosives or retrieval or deposition of objects in hostile environments.

Ordinarily, the satellite is activated by a telecommunication link from an Earth station or perhaps another satellite. If this primary activation method fails to get the equipment started, the proposed backup method would be implemented. The Space Shuttle or other mobile control/service station would project a powerful microwave beam or



A Beam From a Nearby Station first carries raw energy and then the subsystem-activating signals to equipment crippled by the discharged storage batteries. With this scheme, operators can start up the equipment without approaching it under hazardous conditions.

intense light beam toward the disabled equipment (see figure). Rectifying antennas, Shockley diodes, photosensors, or other devices on the equipment would receive the beam energy and convert it to direct current. This electrical power would provide the boost the equipment needs to activate its batteries or solar cells or both. The command signals then would be superimposed on the beam so that the control and communication systems on the equipment could be activated.

At this point, control would revert to the Earth station or other normal remote-control point. Normal deployment of the equipment would resume. To prevent unauthorized startup of the equipment, the Space Shuttle or mobile control/service station would first transmit the normal remote-control security code to the equipment.

This work was done by Kent D. Castle of **Johnson Space Center**. *No further documentation is available.*
MSC-21010

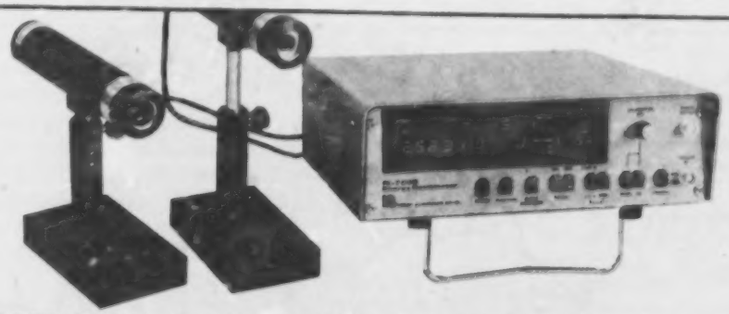
Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Radiation Hardening of Computers

Single-event upsets are reduced by use of oversize transistors.

Computers can be made less susceptible to ionizing radiation by replacing bipolar integrated circuits with properly-designed, complementary metal-oxide-semiconductor (CMOS) circuits, according to a report. CMOS circuit chips can be made highly resistant to single-event upset (SEU), especially when certain



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Rjp-735	Cavity	1.0cm²	$1x10^{-7}$	$1x10^{-2}$W/cm²	±½% (0.4-3μm); +½%, −4% (0.25-16 μm)
Rjp-736	Flat	20.0cm²	$1x10^{-4}$	$1x10^{-3}$W/cm²	±3% (0.4-1μm); +3%, −9% (0.35-11 μm)
Rjp-765	Silicon	1.0cm²	$5x10^{-13}$	5W/cm²	0.3-1.1μm (not flat)

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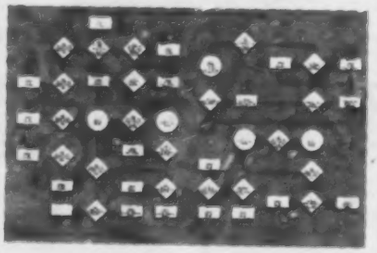

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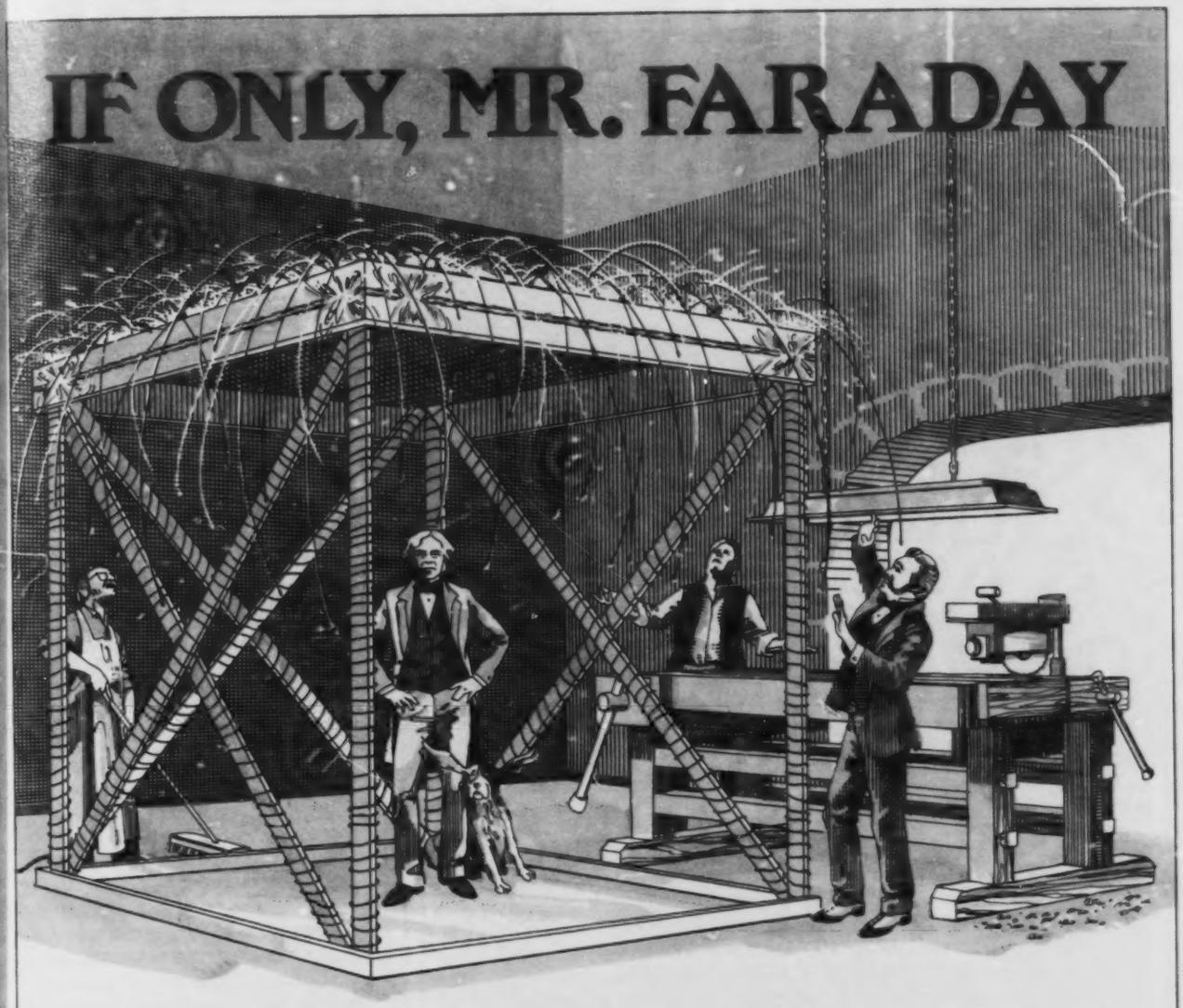

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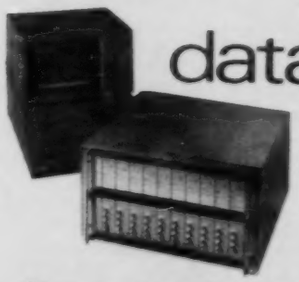

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feedback resistors are incorporated. The redesigned chips also consume less power than do the original chips.

CMOS replacements for nine types of bipolar logic circuits were constructed. Two techniques were used to increase the resistance to radiation. One is the use of oversize transistors. Feedback resistors are also inserted in the regeneration path of most latches to increase the time of responses to particle hits to well beyond the durations of the disturbances.

The use of larger-than-minimum transistors helps in two ways: The increased current drive causes a struck node to be restored more quickly, and the higher gate capacitance permits a corresponding decrease in the size of the feedback resistor required to achieve a given regeneration time. The increase in size beyond the minimum required for sufficient speed, reduces the dependence on resistors to the point where they are not critical to adequate immunity to SEU. Moreover, because the CMOS chips are small relative to area constraints imposed by processing yield, it is feasible to use oversize transistors without making the replacement chips unduly large.

When resistors are used to enhance the resistance to SEU, they are incorporated into the chips by one additional processing mask step; it is thus possible to fabricate in parts with and without the extra resistors in one wafer lot. The resistors are positioned in circuits so that the read-access times of memories and the propagation delays of latches are not significantly degraded. The resistors degrade the computer speed somewhat. For example, the write time for memories and the setup time for latches are increased by about 12 ns and 2 ns, respectively, for a 2901 4-bit microprocessor slice when 80-kΩ resistors are added.

Tests were conducted to determine the linear-energy-transfer (LET) thresholds for the CMOS replacement parts by subjecting them to 165-MeV krypton ions at a minimum fluence of 2×10^7 particles/cm^2 in a cyclotron. All data were taken with a power supply operating at 4.5 V, making the devices more susceptible to SEU than at their normal 5.0 V operation. The LET thresholds of all the tested CMOS circuits, both with and without resistors, were above the desired LET value of 37 MeV/mg/cm^2.

This work was done by Donald K. Nichols, Lawrence S. Smith, and John A. Zoutendyk of **NASA's Jet Propulsion Laboratory** *and Alfred E. Giddings, Frank W. Hewlett, and R. Keith Treece of Sandia National Laboratories. To obtain a copy of the report, "SEU Immune ICs for Project Galileo," Circle 26 on the TSP Request Card.*
NPO-16767

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Circle Reader Action No. 304

Laser Inertial Navigation System

Acceptable accuracy is obtained with short alignment time.

A report describes successful helicopter tests of laser inertial navigational equipment. The tests were conducted over a 3-year period, both in a laboratory and in flight. The inertial system was used as a position/velocity/attitude indicator and later also served as part of an automatic flight-control system.

The inertial-system sensing head includes integrating laser gyroscopes and linear accelerometers. Each laser gyroscope senses the rotation about a single axis in terms of the phase shift between two laser beams launched along opposite paths about the axis. Each linear accelerometer operates similarly, except that the paths and the sensed motion are along the axis.

There are two variations on the sensing-head design: The triad version has three mutually-perpendicular sensing axes, while the tetrad version includes an additional skewed sensing axis along the diagonal of the cube represented by the first three axes. The fourth gyroscope-and-accelerometer set provides redundant sensory data for fault detection and for studies of redundancy management.

The sensing head is of the "strapdown" type; that is, it is simply mounted in the aircraft and not gimbaled. Associated with the sensing head are a control-and-display unit, a system to record flight data, and a dual navigational computer.

The computer program includes provisions for detecting malfunctions in the sensors. As an example, one indication of sensor failure would be that the scalar difference (called the "parity residual") between the skewed-sensor output and the vector sum of the orthogonal-sensor outputs exceeds the background noise by a prescribed amount. When a fault is detected in any of the four axes, the sensor data for that axis can be excluded from the navigation calculation, allowing the system to continue operating with the three remaining sensors.

In the flight tests of the triad and tetrad systems, acceptable navigational accuracy was obtained after computer-controlled alignment procedures lasting 5 minutes or less before each flight. (Alignment is performed with the sensing head in place.) Failure detection using the four-axis parity residual was successful at failure levels far below the noise threshold of flight-sensing requirements.

In the digital navigation-and-control system, the laser inertial equipment provides attitude, position, and velocity information that is combined with information from a microwave landing system and with control signals from the pilot. The processed combination of inputs is fed to the aircraft servocontrol system. Such a navigation-and-control system performed well in automatic-flight tests in which a helicopter landed from straight and level flight by first entering a two-turn descending helix, then emerging from the helix in line with a runway, and then decelerating to a hover 4.7 m above the landing point.

This work was done by Ronald J. Hruby and G. Xenakis of **Ames Research Center**, *Ralph A. Carestia of the University of Southern Colorado, William S. Bjorkman and S. F. Schmit of Analytical Mechanics Associates, Inc., and L. D. Corliss of the U.S. Army Aeromechanics Laboratory. For further information Circle 45 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11473.

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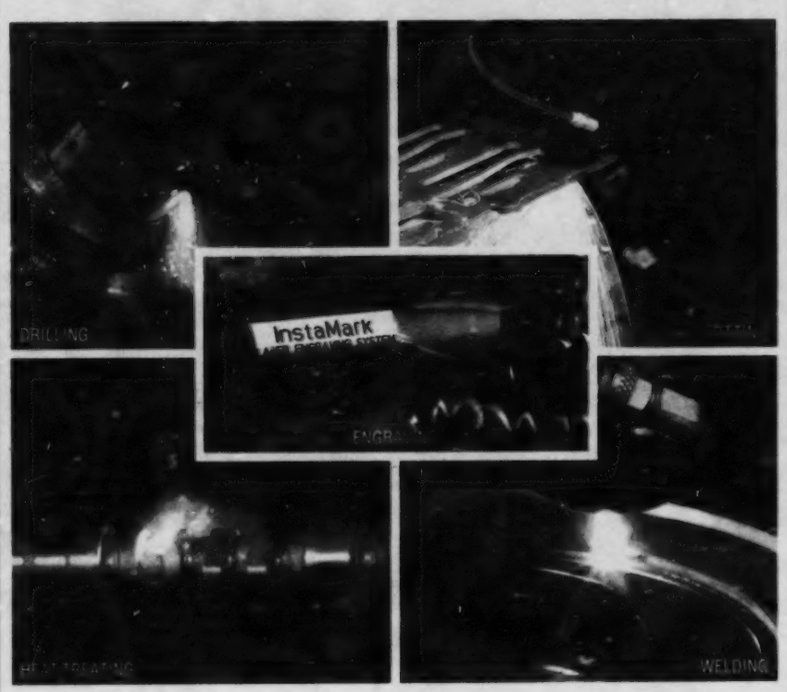

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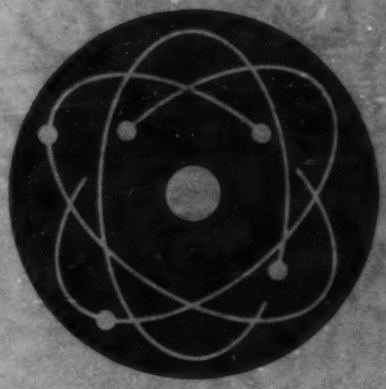
Physical Sciences



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More even spectral dispersion over the detector area makes all wavelengths more distinguishable.

Goddard Space Flight Center, Greenbelt, Maryland

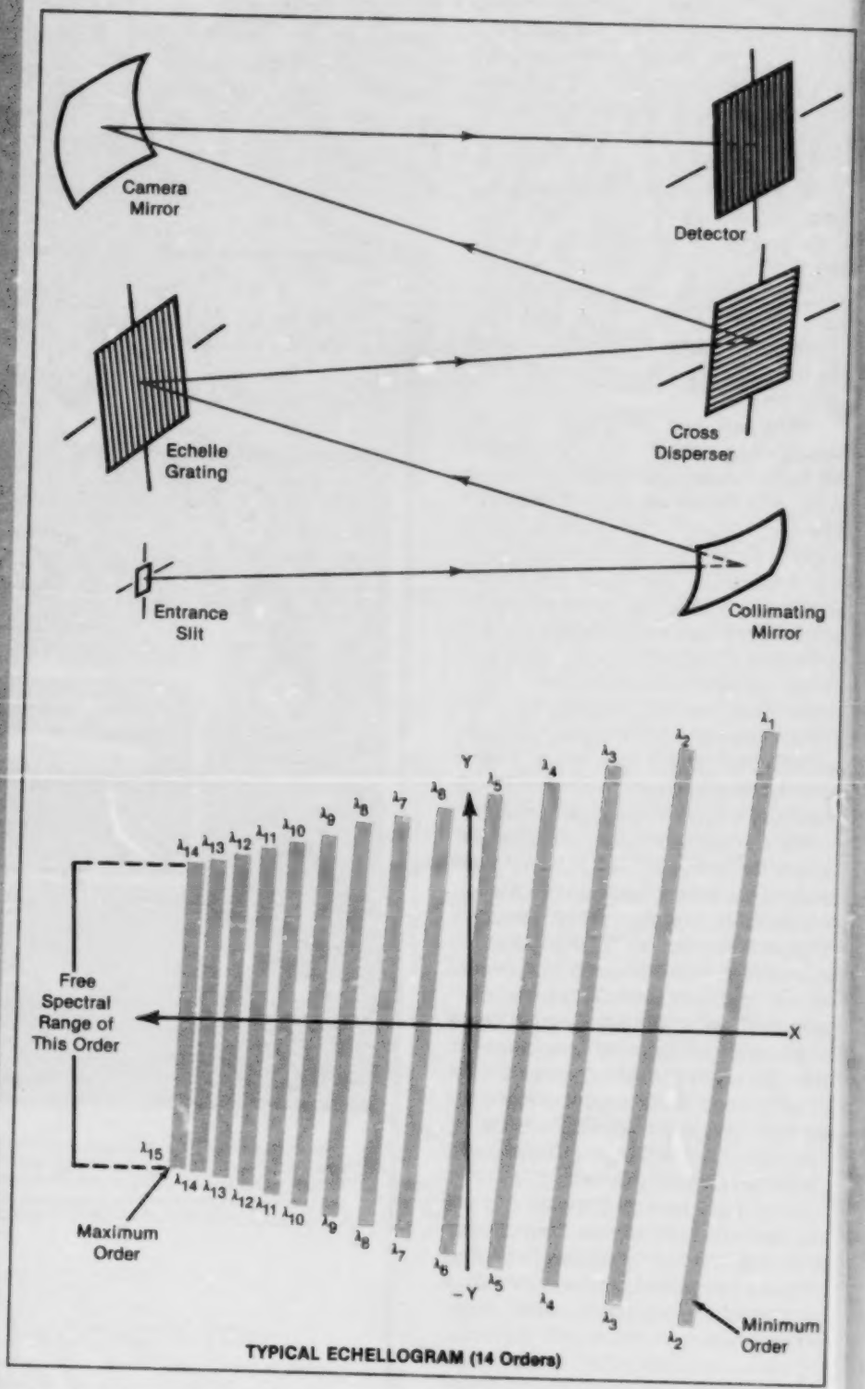
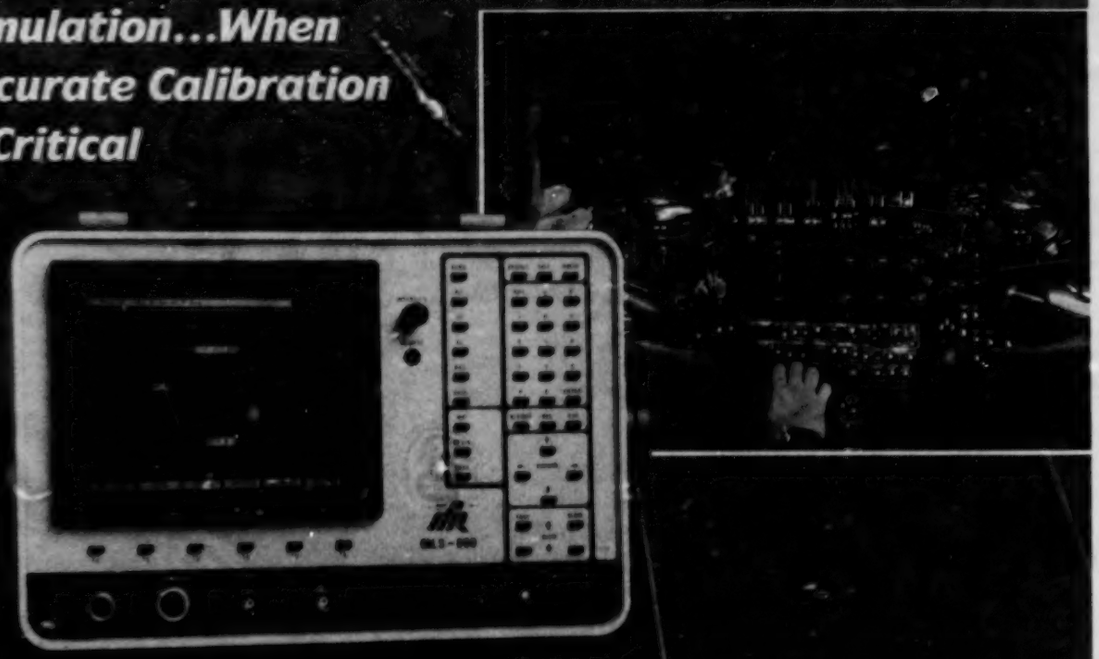


Figure 1. A **Conventional Echelle Spectrograph** (above) includes two diffraction gratings operating in two perpendicular planes. The instrument produces a two-dimensional spectrogram (below) showing several lines that correspond to different diffraction orders.

The Precision Approach to Microwave Landing Simulation...When Accurate Calibration is Critical



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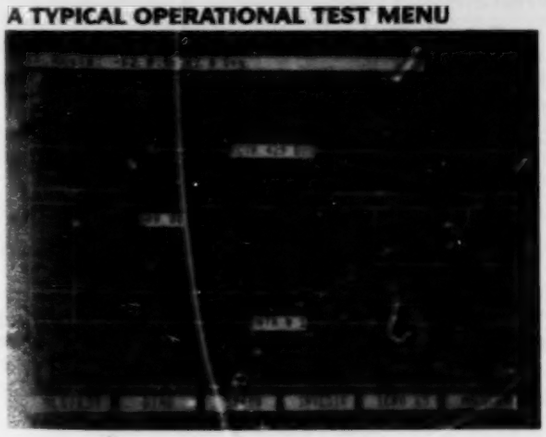

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Circle Reader Action No. 317

A proposed echelle spectrograph would include a grating/prism combination, called a "grism," to make the spectral dispersion over the detector more even than it usually is in such instruments. The instrument performance would thus be improved, with little additional manufacturing effort. Furthermore, since the grism would be placed within collimated light and its faces would be optically flat, it would introduce no aberrations into the optical system.

In a conventional echelle spectrograph (top of Figure 1), collimated light is first diffracted by an echelle grating to a high order in one plane, then diffracted by a second grating (called a "cross disperser") in a perpendicular plane. The resulting dispersion spreads the spectrum out on the detector plane in two dimensions as several diffraction-order lines side by side, with the wavelength varying with its position along each line.

The diffraction angle in each diffraction plane, and therefore the placement of each order line on the detector plane, varies nonlinearly as $\sin^{-1}(C_1 \lambda m + C_2)$, where C_1 and C_2 are constants, m = the diffraction order, and λ = wavelength. If large spectral coverage or resolving power or both are required, then as shown at the bottom of Figure 1, the order lines become crowded near one end of the spectrogram. Crowded order lines tend to make the wavelength lines within the order lines indistinguishable, thereby rendering the instrument useless in the affected portion of the spectrum.

In the improved spectrograph, the cross disperser is replaced by the grating/prism combination of Figure 2. The light from the echelle grating is refracted into the prism, diffracted by the grating, then refracted back out of the prism. The sum of the direction changes introduced by refraction at the prism surface varies with the wavelength and order in such a way that the sum compensates for part of the order-line crowding of the grating.

The final position of each spectral component at the detector is now an even-more-complicated nonlinear function of the angle of incidence, prism vertex angle, prism index of refraction, wavelength, and order. However, the prism parameters can be chosen to reduce the order-line crowding, even to almost completely eliminate the nonlinear effect of the cross disperser. Thus, the orders would be spread out almost evenly, allowing more of the detector area to record useful information. The instrument can therefore be designed for greater spectral coverage, resolving power, or both.

This work was done by Andrew A. Dantzler of **Goddard Space Flight Center.** *For further information, Circle 83 on the TSP Request Card.*
GSC-12977

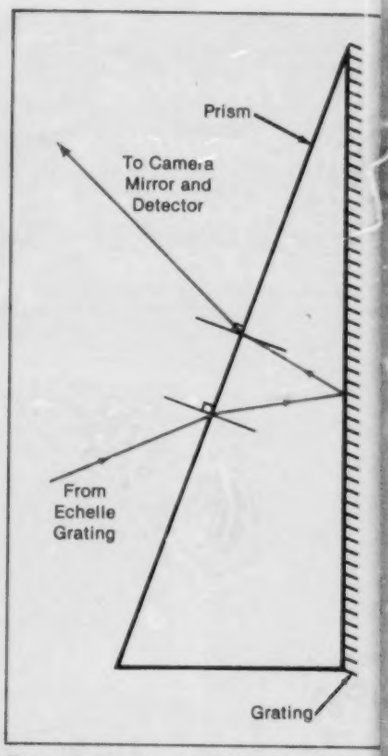


Figure 2. The **Grating/Prism Combination "Grism"** is used in place of the cross disperser of Figure 1. The refractive property of the prism can be exploited to compensate for some or most of the nonlinearity introduced by the grating.

Vacuum-Ultraviolet Intensity-Calibration Standard

A portable light source enables the calibration of spectrometers.

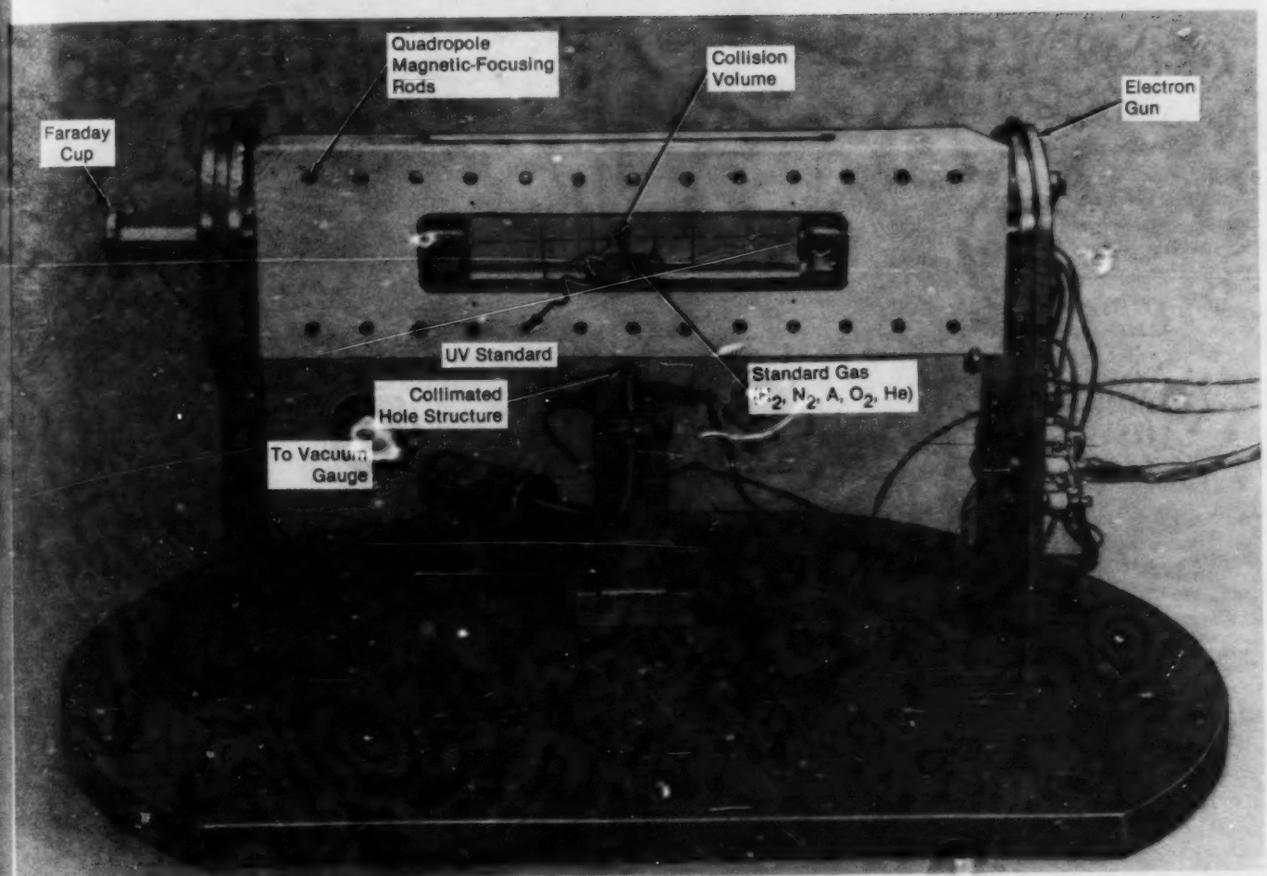
NASA's Jet Propulsion Laboratory, Pasadena, California

Spectrometers equipped with photodetectors can be calibrated on a relative basis in the full vacuum-ultraviolet (VUV) wavelength range of 40 to 200 nm, by use of a simple, compact laboratory source of radiation and a theoretical model that relates the emission intensity as a function of wavelength to the molecular constants of the gaseous emitters in the source. Previously, there were blackbody standards in the visible and near ultraviolet, but there were no intensity-calibration standards in the VUV.

The source in which various gases are excited by electron impact is shown in the figure. In an electron-impact emission chamber, a magnetically collimated beam of electrons of variable energy (1 eV to 1 keV) is crossed with a beam of gas formed by a capillary array. The adjustable background gas pressure varies from 1×10^{-7} to 2×10^{-5} torr (1.3×10^{-5} to 2.6×10^{-3} N/m^2). Inelastic collisions between electrons and molecules cause the emission of photons, which are observed perpendicularly to the electron beam.

This source was used to measure laboratory standard electron-impact VUV spectra for important band systems of H_2 and N_2, which include two Rydberg series of H_2, Lα, and Lβ dissociatively excited from H_2 and the N_2 ($a^1\Pi_g \rightarrow X^1\Sigma_g^+$) band system. The H_2 standard spectrum extends from 80 to 170 nm, and the N_2 standard spectrum extends from 110 to 260 nm. These spectral measurements agreed within 10 percent of those calculated from a theoretical model, which included vibrational and rotation-al structures of the electron-excited systems at the resolution of the laboratory spectrometer. Such a close agreement shows that this source can serve as a relative intensity-calibration standard for VUV instruments in the region of 80 to 170 nm, provided that account is taken of optical-depth effects for foreground abundances greater than 3×10^{12} cm^{-2} with H_2 as the calibration gas.

In a typical laboratory procedure, for example, in calibrating a spectrometer in the range of 80 to 170 nm, the H_2 pressure in the capillary array is 0.1 torr (13 N/m^2), and a 100-eV, 200-μA electron beam is produced by a Pierce electron gun, magnetically focused by quadrupole rods. The electron beam is collected and monitored by a Faraday cup to ensure that all electrons leaving the electron-gun aperture are collected. To be calibrated, the source spectrum is then recorded by the spectrometer. The desired relative



Vacuum Ultraviolet Light (40 to 200 nm) is produced in an electron-impact emission chamber by leading a beam of gas across an electron beam. The photons are observed at right angles to the electron-beam axis.

sensitivity of the spectrometer is the measured spectrum divided by the synthetic (theoretical) spectrum of the same resolution. The flight Galileo Ultraviolet spectrometer and the Spartan Halley Ultraviolet spectrometer were calibrated at the University of Colorado by this portable UV light source.

Current work on argon will allow calibration to be extended to the lower wavelength limit of 40 nm. The absolute calibration can be determined by normalization at a single wavelength by other means: (a) blackbody standard near 200 nm, (b) comparison to a calibrated photodiode, and (c) same electron beam source described above in static gas mode using a standard cross section; e.g., He (58.4 nm).

This work was done by Joseph M. Ajello and Brian O. Franklin of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 32 on the TSP Request Card.*
NPO-16621

Measuring Seebeck Coefficients With Large Thermal Gradients

An apparatus takes measurements and analyzes data automatically.

NASA's Jet Propulsion Laboratory, Pasadena, California

The search for thermoelectric materials for the conversion of heat to power will be aided by a highly automated apparatus that measures Seebeck coefficients rapidly and accurately. Conveniently shaped samples are used, and the results are calculated by a microcomputer and printed out.

The Seebeck coefficient is obtained from short, rod-shaped samples by the "integral" method of measuring the Seebeck voltage, V(T), in which one end of a sample is held at a fixed temperature, T_c, while the other end is varied automatically through the temperature range of interest (up to a maximum temperature, T, of 1,300K). The Seebeck coefficient, S(T), is obtained from $S(T) = dV(T)/dT$.

As shown in the figure, the sample is pressed (by external springs) between a resistance-heated molybdenum cylindrical furnace and a copper water-cooled plate. Thermal insulation between the hot and cold plates is provided by either bulk fiber or, preferably, multiple molybdenum radiation shields. The entire apparatus is inside a bell jar evacuated to about 10^{-7} torr (10^{-5} N/m^2).

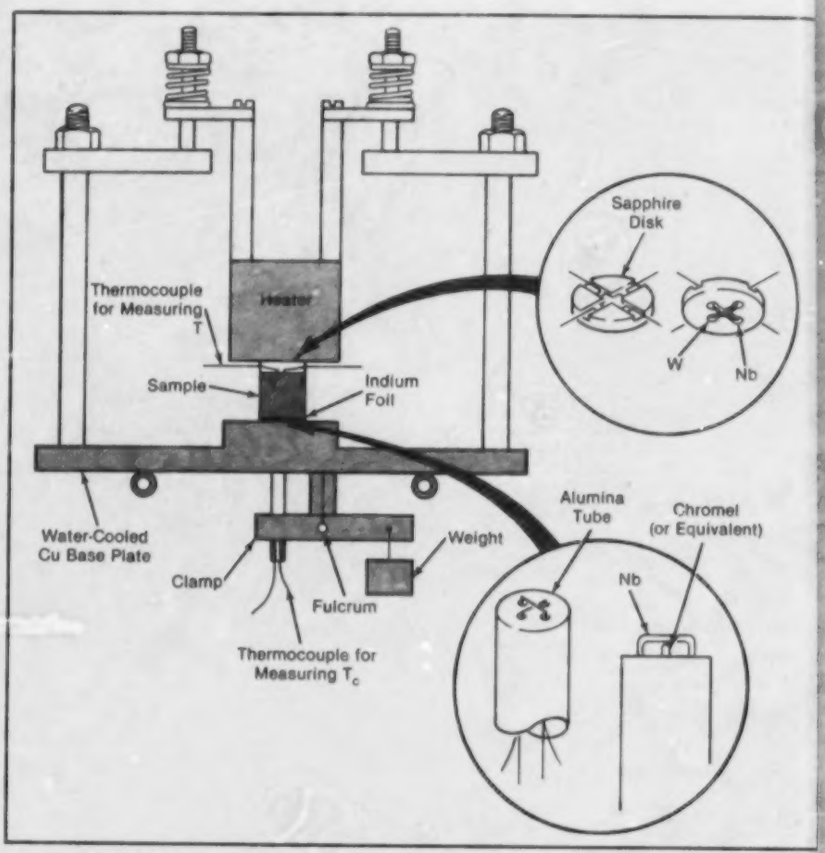
For the cold junction, a single strand of

Nb thermocouple wire is threaded through two diametrically opposite holes of a four-bore Al_2O_3 tube, and a single strand of W Chromel (or equivalent) wire is threaded through the other two holes; the two wires cross at the tube end and form the thermocouple junction. The wires are pressed against the bottom of the sample by means of a lever and a weight. An In washer is used to lower the thermal resistance between the sample and the cold plate.

A similar thermocouple configuration is used for the hot junction, except that the Al_2O_3 tube is replaced by a sapphire button. The external spring pressure on the hot plate presses this junction on the end of the sample. The voltages produced by the two thermocouples provide both T_c and T and the Seebeck voltage, V(T). In this way the ideal is approached of measuring the temperature (T) and the Seebeck voltage at the same points on the specimen.

The temperature of the hot-plate furnace is automatically increased slowly above room temperature by increasing the input from a variable transformer driven by a geared-down electric motor. A W/Nb thermocouple is used to monitor the furnace temperature and provide input to a set-point temperature controller. At a predetermined temperature, the output of the controller causes the motor to reverse and the temperature to decrease slowly back to room temperature. Throughout each cycle, the Seebeck data are fed to a microcomputer; the final results are printed in tabular form and plotted.

This work was done by Charles Wood, Artur Chmielewski, and L. Daniel Zoltan of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 7 on the TSP Request Card. NPO-16667*



In this **Apparatus for Measuring Seebeck Coefficients,** a cylindrical sample is pressed between a heater and a water-cooled baseplate. Thermocouples at opposite ends of the sample provide both the temperatures and the Seebeck voltages.

Sunlight Simulator for Photovoltaic Testing

A flashlamp array and a filter provide spectral irradiance resembling that of sunlight.

NASA's Jet Propulsion Laboratory, Pasadena, California

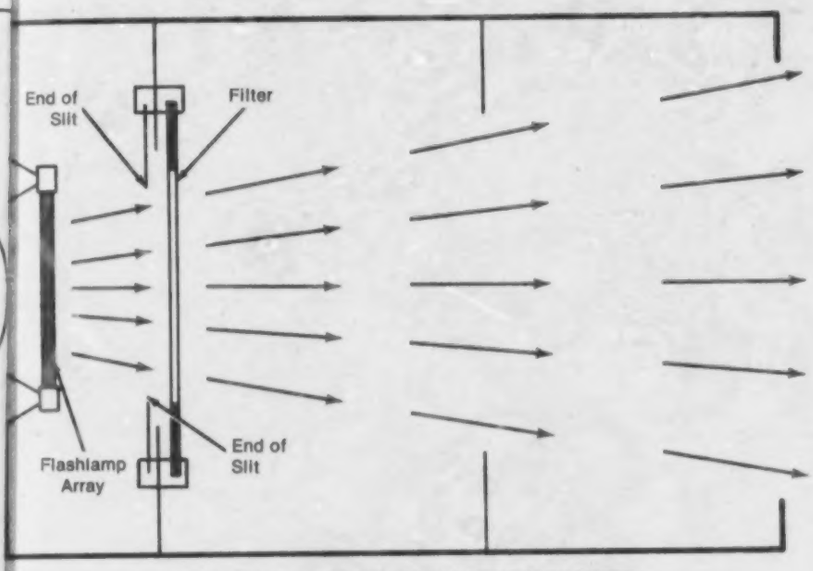
Light with normalized spectral irradiance resembling that of airmass 1.5 sunlight striking the surface of the Earth is produced by use of an ultraviolet filter to modify the output of a set of flashlamps used as a large-area pulsed solar simulator (LAPSS). This filtered LAPSS light allows more realistic measurements of the output of photovoltaic devices when using a silicon reference cell having a different spectral response characteristic.

Spectral mismatches between light sources can cause errors in the measurement of the output of photovoltaic devices. These errors are large when the reference cells used to measure light-source intensities have spectral responses different from those of the photovoltaic devices being tested. The spectrum of the filtered light is more realistic for evaluating such devices, especially the new narrow-band, thin-film devices.

Measurement errors can be reduced to 1 percent by use of a 1-mm-thick Schott GG-395 (or equivalent) filter with a slit sized to insure uniformity of illumination at the target plane and restore the desired intensity. As shown in the figure, the filter reduces the ultraviolet portion of the unfiltered flashlamp irradiance curve, thus producing a curve that averages well with the standard airmass 1.5 global curve.

For five wavelength bands, covering the intervals between 300 nm and 1,100 nm, the minimum ratio of normalized irradiance of the filtered light to that of standard airmass 1.5 global light is 0.884, and the maximum ratio is 1.099. This is substantially better than the ratio range of 0.75 to 1.25 allowed for a Class A solar simulator.

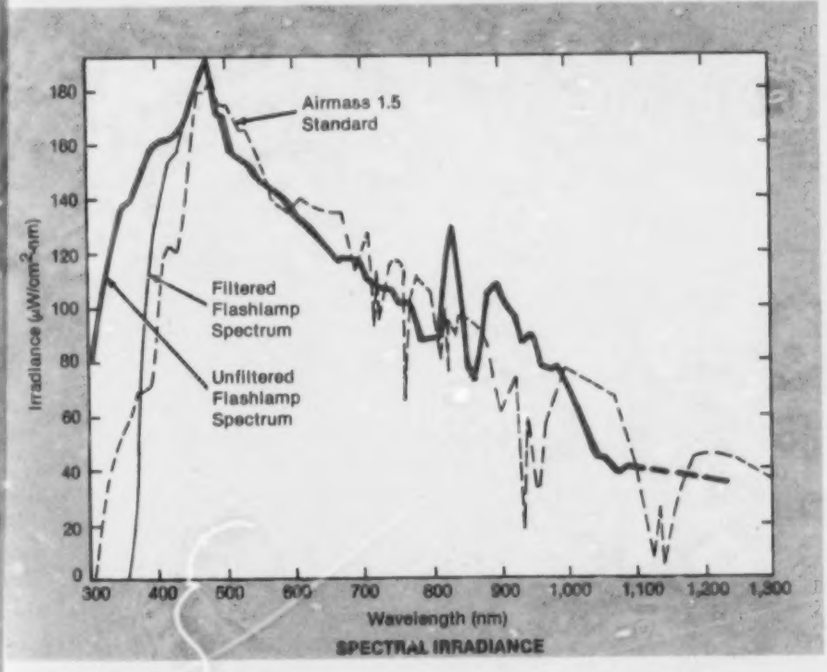
The performance of the filtered LAPSS is also better than that of a Class A simulator in several other regards. The nonun-



LARGE-AREA PULSED SOLAR SIMULATOR WITH FILTER

formity of total irradiance is within 1 percent, vs. 2 percent for a Class A simulator. The total irradiance within a 30° field of view is greater than 99 percent, vs. 95 percent for the Class A unit. Finally, the temporal instability of irradiance is within 1 percent, vs. 2 percent for the Class A unit. There has been no detectable change in the spectral transmission of the filter after 10,000 flashes during 10 months.

This work was done by Robert L. Mueller of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 17 on the TSP Request Card.*
NPO-16696



SPECTRAL IRRADIANCE

A **Filter** reduces the ultraviolet portion of the unfiltered flashlamp spectral curve, yielding an irradiance that averages well with that of standard airmass 1.5 global sunlight.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Electron-Diffraction Analysis of Growth of GaAs

This technique elucidates the mechanisms of GaAs crystal growth.

A report describes experiments that used reflection high-energy-electron diffraction (RHEED) to investigate the behavior of GaAs surfaces during and

after growth by molecular-beam epitaxy (MBE). The experimental results show that dynamic RHEED measurements are useful both as probes of surface and growth kinetics and as methods for determining and reproducing surface and growth conditions.

The experiments were performed in a Riber 1000-2 MBE system. The (001) semi-insulating GaAs substrates were maintained at 600 °C. For all RHEED measurements, the electron beam was incident along the [110] axis of the surface. An off-Bragg angle of incidence caused interference between beams that diffracted from adjacent layers, resulting in high sensitivity to step behavior. Gallium fluxes were determined by measurement of the periods of oscillations in the RHEED pattern during growth; arsenic fluxes were determined by previous calibrations of an ion gauge near the sample position.

In one experiment, the RHEED specular-beam intensity was measured during and after short depositions ranging from a small fraction of a monolayer to several monolayers of Ga while the As pressure was held at 2.2×10^{-7} torr (2.9×10^{-5} N/m^2). This gave an As incorporation rate of 2.9 monolayers per second. After each deposition, the specular beam intensity was measured until it recovered its pregrowth value.

The recovery behavior depends strongly on the amount of Ga deposition. The initial intensity recovery is fastest after the growth of an integral number of monolayers and slowest after half-integral growths. This effect is largest for 0.5 to 1.0 monolayers and still remains significant after 13 monolayers. However, the time to recover completely to the predeposition intensity is longer for integral depositions than for fractional depositions.

The recovery curves generally follow the form

$$I = A_0 - A_1 e^{-t/\tau_1} - A_2 e^{-t/\tau_2}$$

where I is the RHEED intensity, A_0 is the pregrowth intensity, A_1 and A_2 are constants, and τ_1 and τ_2 represent time constants for fast and slow recovery processes, respectively. The least-squares fit of this equation to the data is excellent, except after integral or integral minus 0.12 monolayer depositions.

Another experiment was designed to show the dependence of the RHEED intensity oscillations on the As pressure. At high As flux, the intensity oscillations have a small amplitude, which is rapidly damped out. When the As pressure is reduced, the damping is continuously reduced, while the amplitude of the oscillations first increases and then decreases again at low As pressure. Below an As pressure of 8×10^{-8} torr (1×10^{-5} N/m^2), there are no oscillations, and growth is stabilized by Ga.

These results can be understood by considering the fast recovery process as a rapid smoothing of the growth front and the slow process as the recovery of long-range order in the form of the rearrangement of terraces, the reduction of one-dimensional disorder, or both. The fast process produces the largest change at low As pressure, suggesting the migration of Ga atoms. The slow process is fastest at high As pressure, suggesting the reduction of disorder. The slow recovery after the deposition of 1.0 monolayers indicates that such surfaces are very different from the equilibrium no-growth surface.

This work was done by Blair F. Lewis, Frank J. Grunthaner, Anupam Madhukar, T. C. Lee, and Rouel Fernandez of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "RHEED Intensity Behavior During Homoepitaxial MBE Growth of GaAs and Implications for Growth Kinetics and Mechanics," Circle 3 on the TSP Request Card.*
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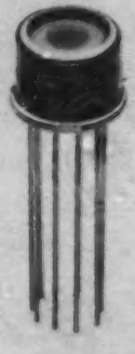

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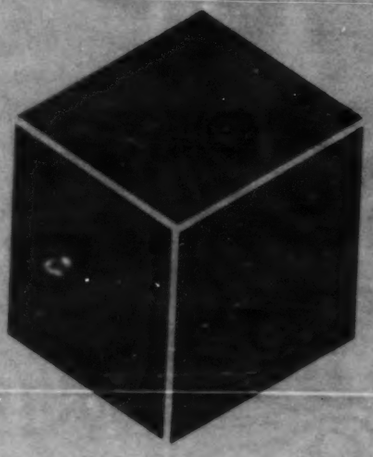

Hardware, Techniques, and Processes

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Etching Silicon Films With Xenon Difluoride

Microscopic circuit structures are prepared for probing.

NASA's Jet Propulsion Laboratory, Pasadena, California

Xenon difluoride removes relatively large amounts of silicon from integrated-circuit or solar-cell structures while leaving SiO_2, Si_3N_4, Al_2O_3, and other compounds intact. The etching technique using XeF_2 was developed to aid studies of the physical and chemical properties of interfaces between silicon and compounds of silicon or other elements in such structures. Using the XeF_2 technique, a silicon wafer with an oxide layer can be reduced in thickness from the standard 300 μm to as little as 10 nm without adversely affecting the oxide.

XeF_2 is a white solid with a vapor pressure of 4.5 torr (6×10^2 N/m^2) at room temperature. It is allowed to sublimate in a vacuum chamber containing the specimen to be etched (see Figure 1). The etching efficiency of XeF_2 in Si is only about 1 percent per molecular impact. The etching rate is increased, however, by balancing the partial pressure and flow rate of XeF_2 in such a way that the average number of collisions of an XeF_2 molecule with the sample is of the order of hundreds.

The XeF_2 flows from the solid source

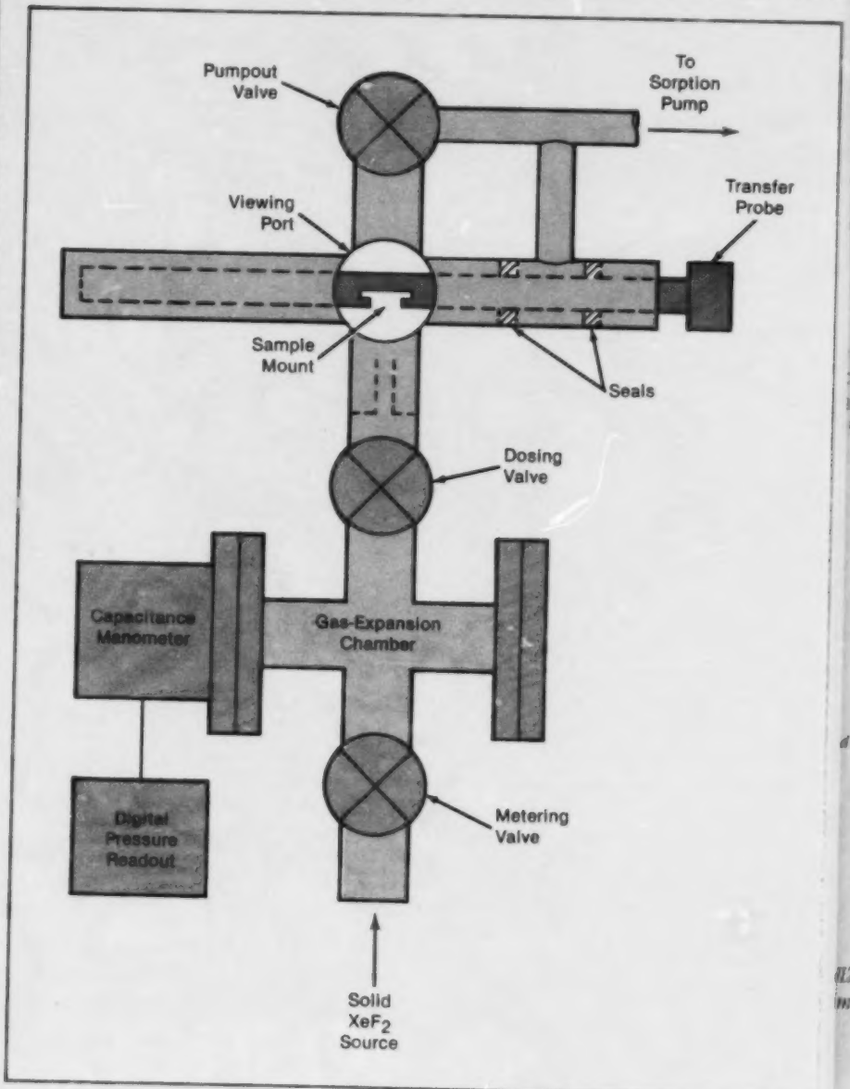
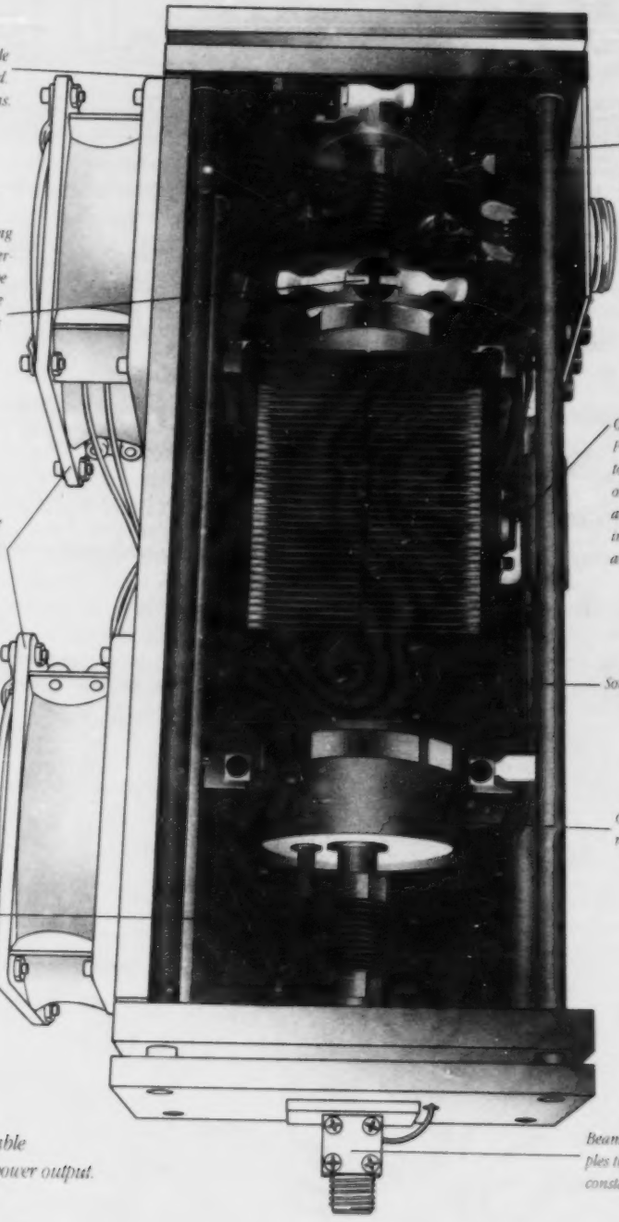


Figure 1. In the **Etching Apparatus,** solid XeF_2 is sublimated in a vacuum, then allowed to flow over the sample at a controlled rate and pressure.

For companies in search of excellence: We invite you to compare he ILT 5000 series argon laser to any other. If that's possible.



Interlock safety switch down anode and cathode when cover is removed. ies with BRH regulations.

Mirror Adjustment gimbal Allows single line models to utilize adjustable littrow prism to obtain 100% spectral purity

ermostat controls cooling and monitors tube temper- . Fans turn on when tube operating temperature urn off only after tube is ely cooled down. As a the tube can warm up ol down faster.

Overtemp interlock Plasma tube heatsink is monitored by a thermostat. If tube overheats, the power to anode and cathode shuts down, protecting system against fan blockage and failure.

igh volume fans provide M of cooling air at each plasma tube where it's eeded.

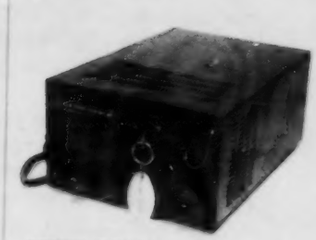
Solid invar rod resonator design.

Ceramic-metal end shroud gas reservoir

al cavity.

5000 series is available to 100mW argon power output.

Beam splitter/photo diode samples the beam and maintains constant power output.



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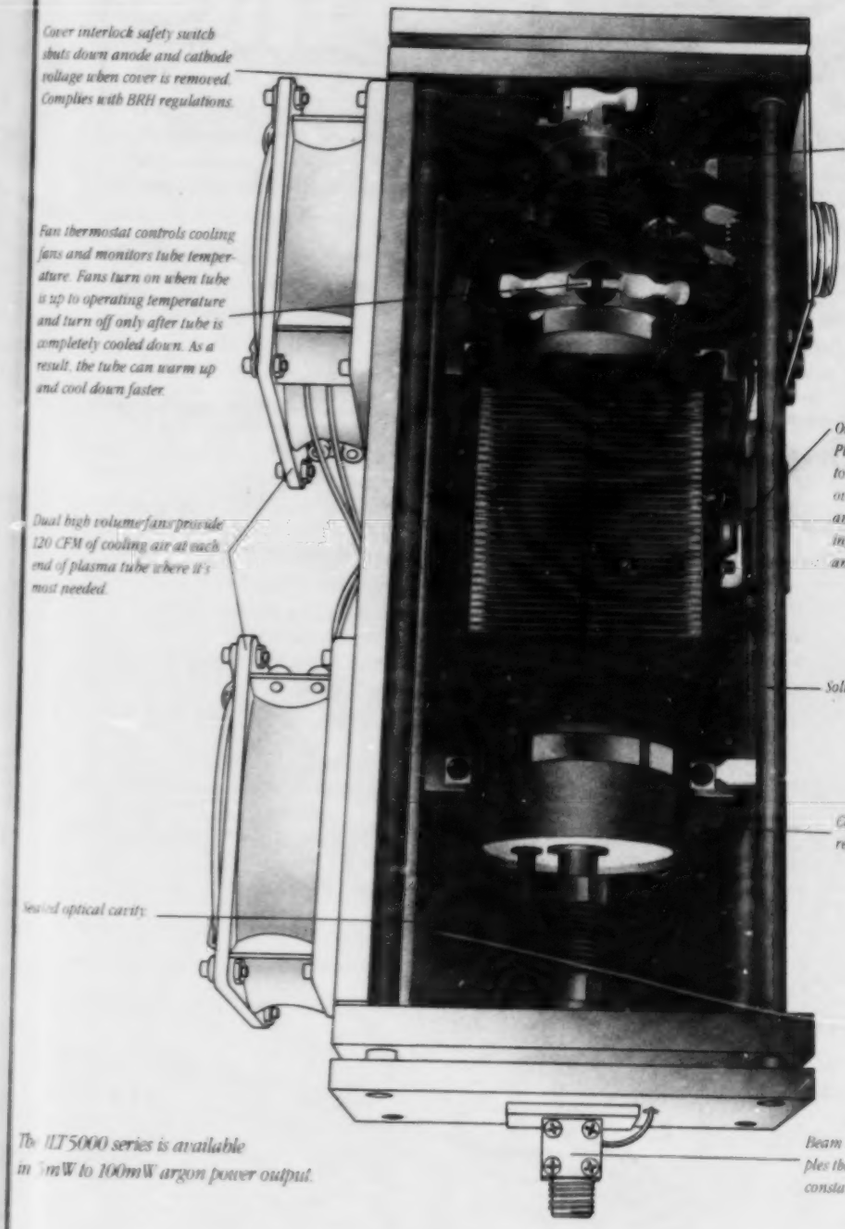
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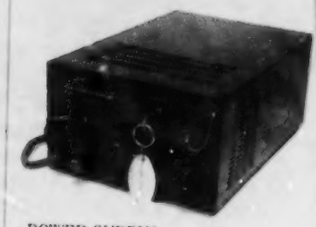

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Ion Laser Technology

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through a metering valve into an expansion chamber, the pressure in which is monitored. At the appropriate pressure, a dosing valve is opened to allow the XeF_2 to impinge on the sample at the calibrated rate.

The sample mount is part of a sealed transfer probe. The sample is cooled to under 0° C to insure the uniformity of etching. A viewing port in the chamber makes it possible to observe the process directly or to use a laser-based thickness-measuring system.

Figure 2 shows an application of the technique. In this case, the objective is to study the interface between a 50-Å layer of SiO_2 and a 1,500-Å layer of Al deposited on a phosphorus-doped wafer of [100] Si. First, the front (aluminum) surface is bonded with indium solder to a gold-plated sample platen. The oxide is stripped from the exposed back surface by etching with a solution of $HF:C_2H_5OH$. The sample is then transported under N_2 to the XeF_2-etching chamber.

The entire silicon layer is removed in 6 to 10 hours. After the XeF_2 etch, the sample is transferred in air to a wet-etching station coupled to an X-ray photoelectron spectrometer. The spectrum is recorded while the SiO_2 is slowly etched away. In one such series of experiments, the spectroscopic studies showed that the interface between the Al and the SiO_2 is atomically abrupt if unannealed and includes a 0.6-nm-thick layer of Al_2O_3 if annealed.

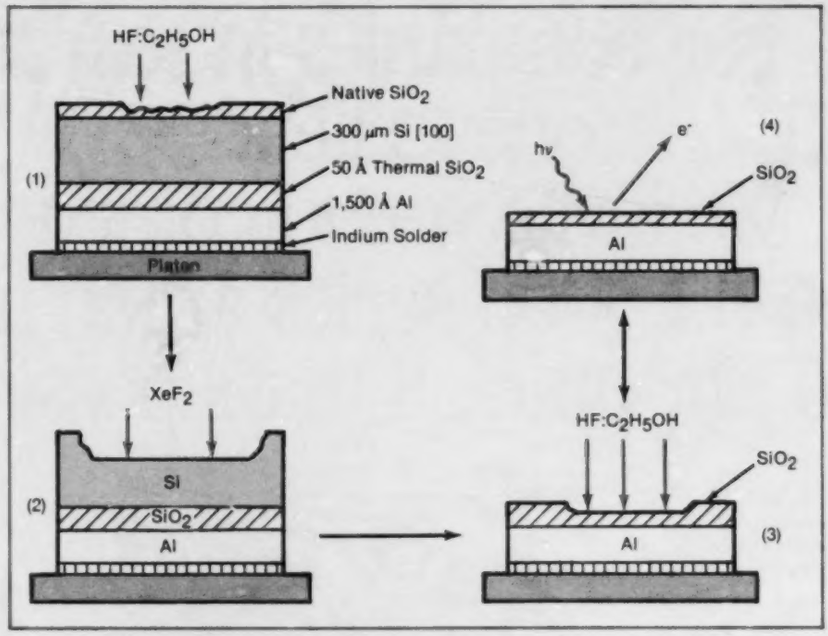


Figure 2. A **Wafer Is Etched** from the back to expose SiO_2 and Al layers for spectroscopic analysis of the SiO_2/Al interface.

This work was done by Michael H. Hecht of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 11 on the TSP Request Card. NPO-16527 and NPO-16528*

Preventing Delamination of Silverized FEP Films

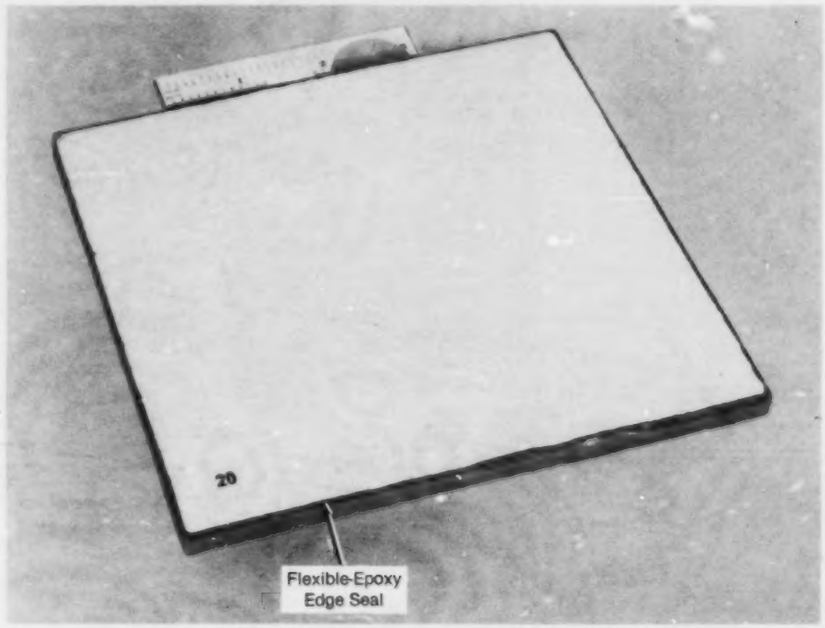
Edge treatment inhibits attack by moisture.

Lyndon B. Johnson Space Center, Houston, Texas

A novel procedure overcomes delamination of a silver-coated fluorinated ethylene/propylene (FEP) film on an aluminum substrate. FEP presents special difficulties with regard to metalization because it is formulated to actually prevent adhesion.

The delamination of untreated assemblies is apparently due to attack by moisture that migrates through the silicone adhesive between the silver and the FEP. The conclusion that failure was not a result of residual stress — perhaps from processing or simply from differential thermal expansion of the laminated layers — was reached after an extensive test program.

The new technique prevents delamination by sealing the edges where delamination starts. To ensure adhesion, the surface to be sealed is carefully prepared. The edges are abraded lightly with sandpaper to provide a roughened surface for mechanical bonding to the edge-sealing material. A bead of flexible epoxy about one-sixteenth inch (1.6 mm)



Samples of Aluminum/FEP/Silver Laminate survive humidity tests and other environmental tests when the edges of the layers are covered by an epoxy bead.

wide is applied with a syringe so that the edges of the metalization, FEP layer, and film-to-substrate adhesive are covered (see figure).

The method is easy to implement, even in the field as a repair procedure. It withstands a variety of environmental tests, including heat and vacuum testing for 24 hours, moisture testing at 95 percent relative humidity for 5 days, and 3 weeks total water immersion at room temperature. Untreated laminates, in contrast, deteriorated seriously during such tests.

This work was done by Larissa Domnikov, Judy May, and Roberto Gallego of Hughes Aircraft Co. for **Johnson Space Center.** *For further information, Circle 38 on the TSP Request Card.*
MSC-20460

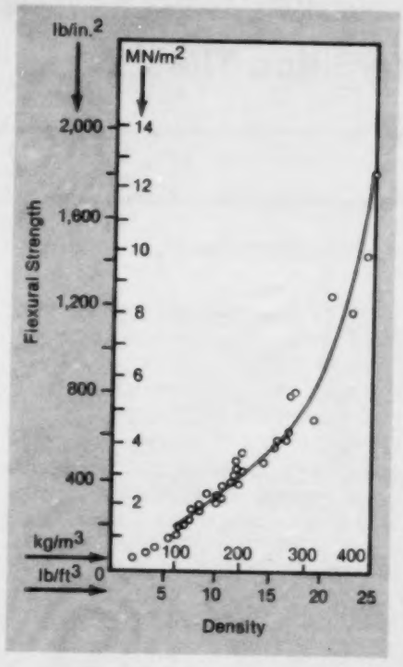
Lightweight Ceramic Insulation

A fiber burnout process yields low densities.

Lyndon B. Johnson Space Center, Houston, Texas

A rigid ceramic insulation has a density of 2 to 6 lb/ft^3 (32 to 96 kg/m^3) — low enough that it can replace flexible insulation in applications where low weight is essential. In contrast with the loose fibers or blankets of flexible insulation, the new insulation does not pack together or shift. It is thermally stable, and, with a flexural strength of 25 to 75 lb/in.^{2} (170 to 500 kN/m^2), it retains its shape under light loading (see figure). Originally developed for use on the Space Shuttle and other spacecraft, the rigid insulation can be machined to the requisite shape and bonded in place.

The low density is attained by a process of sacrificial burnout. Graphite or carbon fibers are mixed into a slurry of silica, alumina, and boron-compound fibers in amounts ranging from 25 to 75 percent of total fiber content by weight. The mixture is formed into blocks and dried. The blocks are placed in a kiln and heated to 1,600° F (870° C) for several hours. During this time, the graphite or carbon fibers slowly oxidize away, leaving voids and thereby reducing the block density. Finally, the blocks are heated to 2,350° F (1,290° C) for 90 minutes to bond the remaining ceramic fibers together.



The **Flexural Strength** of lightweight rigid insulation (solid dots) follows the curve for higher density ceramic tiles of the same composition (small circles).

Before the graphite or carbon fibers are added to the casting slurry, they are chopped and dispersed in deionized water. Graphite and carbon were chosen as the materials for the burnout after experiments with cotton and nylon fibers. The graphite and carbon fibers proved to be more compatible with the rigid-insulation manufacturing process.

This work was done by William H. Wheeler and John F. Creedon of Lockheed Missiles & Space Co. Inc. for **Johnson Space Center.** *For further information, Circle 56 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20831.

Tougher Addition Polyimides Containing Siloxane

Laminates show increased impact resistances and other desirable mechanical properties.

Langley Research Center, Hampton, Virginia

Aromatic addition polyimides have been developed as both matrix and adhesive resins for applications on future aircraft and spacecraft. Addition polyimides offer distinct advantages over linear polyimides, being processable in the form of short-chained oligomers end-capped with latent cross-linking groups. One particularly attractive, commercially available addition polyimide results from the addition polymerization of a maleimide-terminated prepolymer prepared by the reaction of a bismaleimide with an aromatic diamino compound. However, addition polyimides of this kind tend to be highly cross-linked, insoluble, and extremely brittle on curing.

A process has been developed to obtain a bismaleamic acid from the reaction of a diaminosiloxane and maleic anhydride in a 1:2 molar ratio. The bismaleamic acid may be extended by the reaction of the diaminosiloxane with maleic anhydride in a 1:1 molar ratio, followed by the reaction with half this molar ratio of an aromatic dianhydride. The bismaleamic acid may also be extended by the reac-

tion of the diaminosiloxane with maleic anhydride in a 1:2 molar ratio, followed by the reaction with half this molar ratio of an aromatic diamine (Michael-addition reaction).

The oligomer thus forms melts in the temperature range of 80° to 120° C and cures between 140° and 170° C. It can be blended with commercially available bismaleimides, with which it is compatible. All forms of the oligomer can be imidized at 130° C due to the flexibility introduced by the siloxane group and increased basicity of the aliphatic amine group, which enhances the ease of cyclization. (Oligomers of aromatic diamines require cyclization at such higher temperatures as 180° to 200° C, resulting in some isomerization to the fumaric group. Acetic acid left associated with the resin after chemical cyclization may degrade the polymer at the higher temperature where curing is effected, resulting in reduced strengths.)

Composites prepared from the oligomers can be thermoformed at elevated temperatures after an initial molding in the temperature range of 175° to 200° C due to the lowered melting temperatures. A range of service temperatures results from blending the oligomers with various bismaleimides in different proportions.

The resins can be used to coat graphite woven cloth. After drying, the resins can be thermally imidized to give material with drape and tack, and which can be cut easily and formed into shaped layups. These layups may then be molded under heat and pressure to give the desired laminate. Such laminates have excellent properties in terms of glass-transition temperatures, flexural strengths and moduli, and short-beam shear strengths. Also, impact resistances are improved over those of the unmodified bismaleimide, showing a significant increase in toughness.

This work was done by Terry L. St. Clair of **Langley Research Center** *and Shubha Maudgal of the National Research Council. For further information, Circle 20 on the TSP Request Card.*
LAR-13304

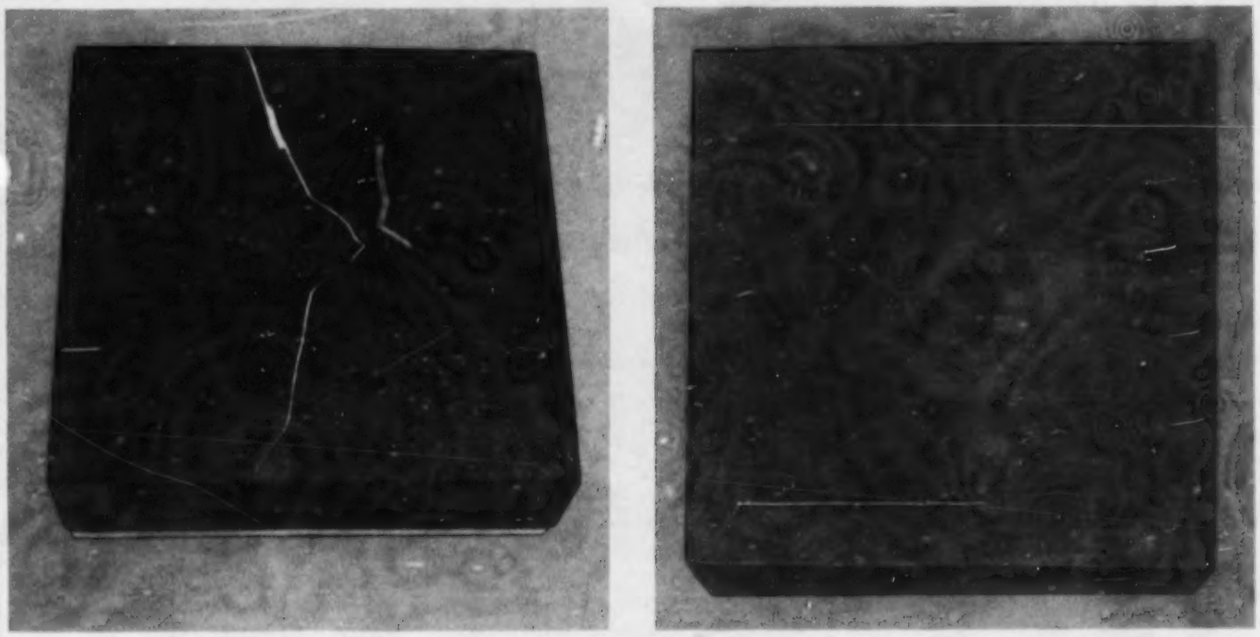
Fast Glazing of Alumina/Silica Tiles

This technique prevents cracking of substrates or coatings.

Lyndon B. Johnson Space Center, Houston, Texas

A new technique for applying a ceramic coating to fibrous silica/alumina insulation tiles prevents cracks and substantially reduces firing time. This technique can be used to repair tiles with damaged coatings and possibly could be used in heat-treating objects made of materials having different thermal-expansion coefficients.

The ceramic coating is applied to tiles made of alumina and silica fibers. In the previous glazing technique, the coated tiles were heated for 95 minutes in a roller-hearth kiln at 2,250 °F (1,232 °C). On various tiles of 22-percent alumina and 78-percent silica, the coatings did not crack. However, on HTP-12 tiles [45-percent alumina, 55-percent silica, density 12 lb/ft^3 (192 kg/m^3)], both the coatings and the substrates cracked (see left side of figure). This cracking is attributed to the difference between the coefficients of thermal expansion of the coatings and the substrates: The coating has a coefficient of 6.07×10^{-7} (°F)$^{-1}$ [10.9×10^{-7} (°C)$^{-1}$], while the substrate has a coefficient of about 23×10^{-7} (°F)$^{-1}$ [41×10^{-7}



Surface Cracking (left) was evident after a ceramic-coated 45-percent alumina/55-percent silica tile, fired at 2,250 °F (1,232 °C) for 95 minutes, was removed from a glazing kiln. No surface cracking (right) occurred in an identical tile fired at 2,372 °F (1,300 °C) for 1.5 minutes, cooled to room temperature, and then fired at 2,660 °F (1,460 °C) for 1.5 minutes.

(°C)-1].

To reduce the thermal stresses in the tile being coated, a high-temperature, short-time firing schedule was implemented. Such a schedule allows the coating to mature while the substrate remains at a relatively low temperature, thereby reducing the stress differential between the coating and substrate.

To test this approach, a 45/55 alumina/silica tile of 6 by 6 by 2 in. (15 by 15 by 5 cm) was heated for 1.5 minutes at 2,372 °F (1,300 °C), cooled to 75 °F (24 °C), then exposed to 2,660 °F (1,460 °C) for another 1.5 minutes. As shown on right side of the figure, no coating or substrate fractures were observed. The conditions were not optimized for this tile and coating, and other temperature/time combinations might be satisfactory.

In addition to eliminating cracks, the new approach has the advantage of increasing production rates, because the firing time is substantially reduced. This technique might allow the elimination of the machining offsets currently applied to all tiles to allow for tile shrinkage during heating. Thus, the tiles might be machined to final (net) dimensions, with a potential saving of material and machining time. This technique also could be used to repair tiles with damaged coatings, because sections of the tiles could be glazed without affecting the substrate dimensions.

It should be noted that this concept is applicable only to thin coatings because of the need to heat the coating rapidly. Moreover, because the coating layer is subjected to severe thermal stress during flash heating and rapid cooling, this technique might not be suitable for coatings that cannot tolerate thermal stresses.

This work was done by John F. Creedon, Edward R. Gzowski, and William H. Wheeler of Lockheed Missiles & Space Co., Inc., for **Johnson Space Center.** *No further documentation is available.*
MSC-20976

A Method for Characterizing PMR-15 Resin

The change in composition with aging makes analysis essential.

Lewis Research Center, Cleveland, Ohio

A quantitative analysis technique based on reverse-phase, high-performance liquid chromatography (HPLC) and paired-ion chromatography (PIC) was developed for PMR-15 resins. PMR-15 resin has gained acceptance as a matrix resin in carbon-fiber composites requiring thermo-oxidative stability at temperatures up to 600 °F (320 °C). Verification of proper resin formulation and analysis of changes in resin composition during storage are important to the manufacturers of PMR-15 polymer matrix composite parts.

The freshly-prepared resin solution consists of three monomers: BTDE, MDA, and NE, which are dissolved in methanol. A prepreg is formed by coating carbon fiber fabric with the monomer solution and then evaporating the methanol. Composite parts are manufactured by assembling plies of prepreg and curing at high temperature.

The processability and performance of the PMR-15 resin depend on its composition. However, the composition of the resin solution and prepreg changes as the solution is aged. The change is a result of the premature reaction of the monomers with each other, as well as of the reaction of the monomers with methanol in the solvent and water from the atmosphere. The components of the aged solution exhibit a wide range of molecular properties, such as molecular weight, polarity, solubility, and dissociation constant. It is difficult to find a single separation technique

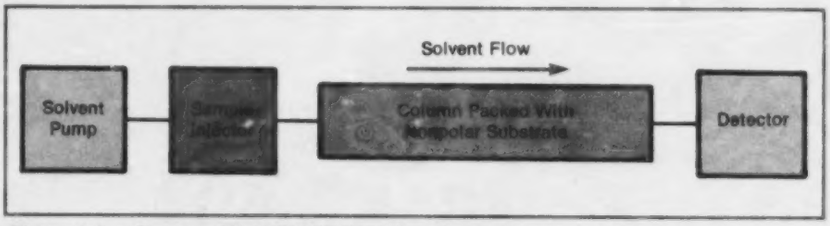


Figure 1. In a Reverse-Phase HPLC Experiment, a polar solvent containing the material to be analyzed is passed through a column packed with a nonpolar substrate.

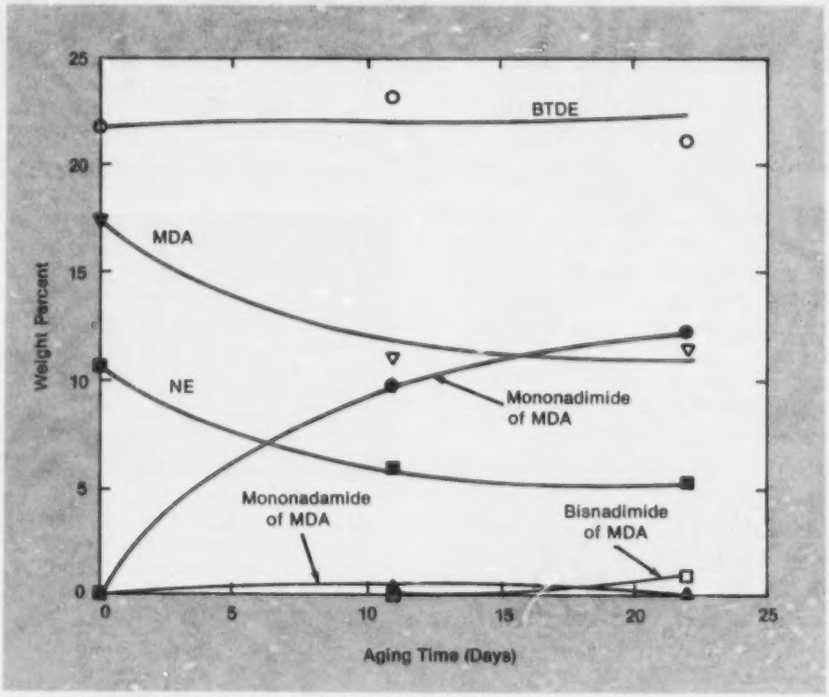
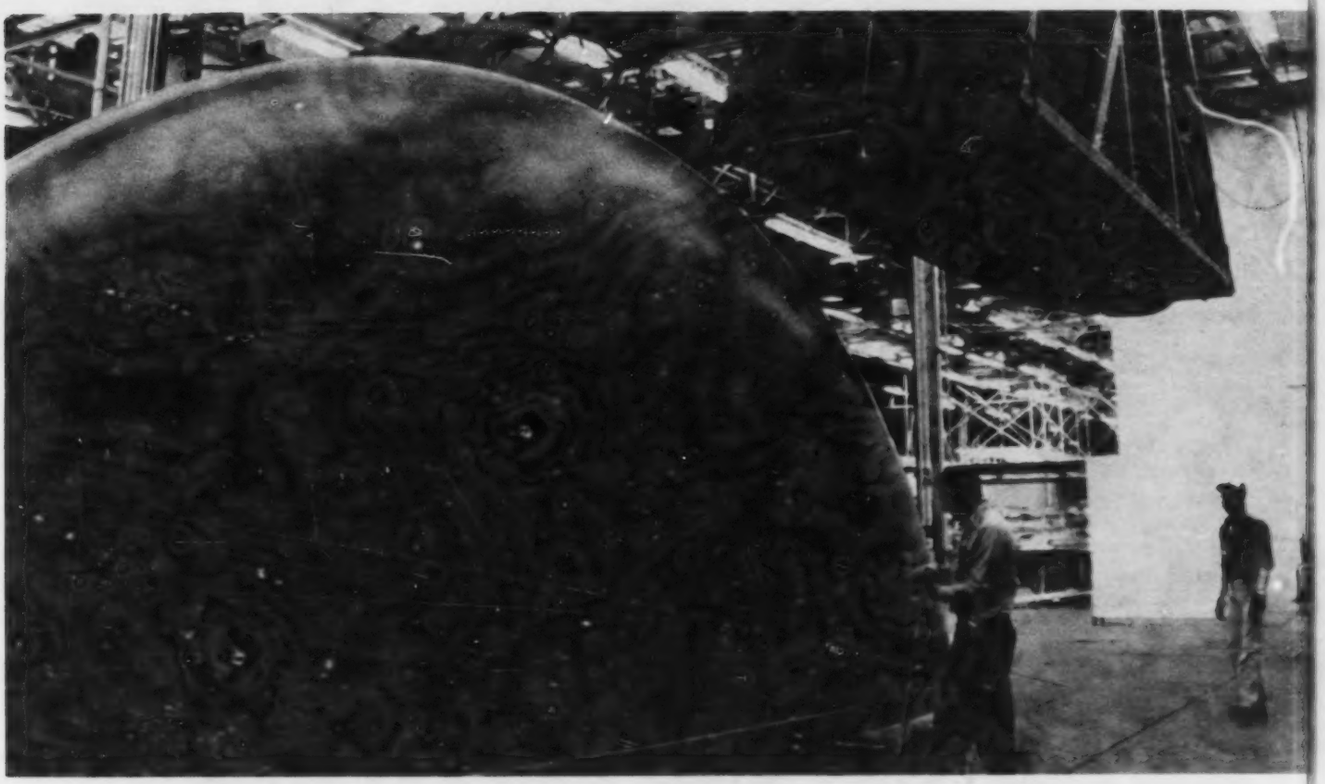


Figure 2. The Composition of a PMR-15 Resin of 50 weight percent changes as the resin ages at room temperature.

Introducing a revolutionary new composite materials tooling system



ToolRite® is a complete tooling materials system that uses low cure temperature prepregs formulated exclusively for tooling. Compared with conventional wet lay-up, it is faster, cleaner, and easier to handle. Tool life is 500% longer. And, being a prepreg system, it assures uniform resin distribution, virtually free of voids and pockets, so thermal cycling has less effect. Heat distributes evenly. Warping is 70% less.

Compared to metal tooling, the ToolRite System provides exceptional dimensional accuracy and thermal stability. Tools and parts heat up and cool down together, at the same rate. Damage and distortion are practically eliminated. Parts come off the tool faster, too.

And because of lower mass, the ToolRite System saves energy—whether you cure by vacuum bag or autoclave.

The ToolRite System cures completely on a master model at 200° to 210°F. It can be removed from the master and post-cured, free-standing, at 350° to 375°F—with service temperatures of more than 400°F.

ToolRite is no ivory tower idea fresh from the drawing board. It is already in use in more than 2,000 tools throughout the aerospace industry worldwide. Here is how two of these users are benefiting from the unique properties of the Fiberite ToolRite System.

Shell lay-up time on the AWACS radome tool was cut an estimated 40% due to fewer plies of thicker, more easily applied material.

One of the world's largest high temperature fiberglass/epoxy tools, the AWACS radome lay-up mandrel is 12½ ft. high, 5½ ft. wide and 30 ft. long at the base. In the past,

ToolRite,® from Fiberite

with wet lay-up, Boeing fabricated the mandrel in two sections and cured each half separately. Thus, there were three cure cycles–Left, Right, and Spliced. With the ToolRite System, as specified by Boeing, the halves can be laid up *and spliced*, then cured in a single cycle. This saves four cycles when building the pair of mandrels required.

Large size and close dimensional tolerance make such a tool expensive to fabricate. But, with the ToolRite System, Boeing has been using the tool for three years and still does not see the end of its useful life. Also, compared with previous tooling, labor for tooling rework to retain vacuum integrity has been cut more than 90%.

As a result of the change from wet lay-up to the ToolRite System, physical properties of the tool have improved greatly. Flexural strength at 350°F is nearly twice that of the previous systems.

"To date, we have over 500 cycles on some of our prepreg tools with no indication of leakage or thermal shock cracks."
R.T. Williams, Manager
Composites and Bonded Structures
Teledyne/Ryan Aeronautical

Ray Williams knows prepreg tooling. He has more than 700 ToolRite tools in inventory at Teledyne/Ryan.

"If you're building graphite, aramid or glass parts, you must match the thermal characteristics of the tool with the part," Williams says. "With interlocking curvatures, projections and tight radii, the tool and the part must expand and contract at the same rate, or you lose dimension."

Uniform resin distribution is important, according to Williams, because resin-rich areas act as a heat sink subject to thermal shock, resulting in premature tool failure. "Using graphite prepreg, we project the life of our tools somewhere near 750 cycles. In addition, the tools are light, and easy to handle and store."

Designing with the ToolRite System has significant advantages over traditional design, according to Williams. "Designing one structure of composite tooling, we've been able to totally design out 11 different components. By eliminating part count and secondary operations, you can really begin to save money," he says.

Is it possible to make an asymmetric part with composite tooling? Using the ToolRite System, Teledyne/Ryan Aeronautical designed this split graphite tool used to fabricate an engine intake duct for the AH-64 attack helicopter. Harbor Patterns, Inc., Los Alamitos, CA, built the tool.

You can get details on the ToolRite Prepreg System for composite tooling–and arrange a technical briefing for your management and an in-shop demonstration–just by picking up your phone. Call Clint Juhl or Kris Ralph at (714) 639-2050, and describe your project. Or use the coupon below.

Add Beech Aircraft to the growing list of ToolRite System users, which already includes Boeing, MBB, CASA (AirBus), BAe, Dassault and Teledyne Ryan. The upper and lower wing skin tools for the Beech Starship I (above) were fabricated using this revolutionary new prepreg tooling system for composite parts.

☐ Please send me a *copy of your brochure showing step-by-step tool fabrication procedures using ToolRite Prepreg System.* I am considering ToolRite materials for the following areas:

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☐ *Military Aircraft*	☐ *Recreational*
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suitable for all components. Some of the components are not readily isolated in pure form. This makes quantitative analysis difficult since standard samples are not available.

A schematic diagram of the experiment is shown in Figure 1. In reverse-phase HPLC, a polar solvent flows through a column packed with a nonpolar substrate. A molecule passing through the column will spend some time dissolved in the flowing solvent and the remaining time adsorbed on the substrate. When a sample containing several components is injected into the column, its pure components elute from the column in order of decreasing polarity.

Components which are ionized in solution do not adsorb onto the nonpolar substrate and are not separated by reverse-phase HPLC. Ionized components can be separated by paired-ion chromatography (PIC). The addition of a PIC reagent to the solvent during a reverse-phase HPLC experiment results in the separation of the ionized components without affecting the separation of the nonionized components. This approach was used to obtain complete separation of all components in aged PMR-15 resin.

Response factors were determined for quantitative analysis. The composition of a PMR-15 resin solution was measured as a function of room-temperature aging time (Figure 2). The composition of resin dissolved from a commercial prepreg was also measured. This technique appears to be especially suitable for commercial use by the manufacturers of high-performance composite components.

This work was done by Gary D. Roberts and Richard W. Lauver of **Lewis Research Center.** *For further information, Circle 47 on the TSP Request Card.*
LEW-14253

Reinforcing the Separators for Lithium/Carbon Cells

A backing can prevent the tearing of the very thin separators during cell assembly.

NASA's Jet Propulsion Laboratory, Pasadena, California

The fabrication of lithium/carbon batteries can be simplified by the attachment of perforated nickel-foil, graphite-cloth, or graphite-paper backings to the glass-fiber separators. These separators are so frail that they are easily torn during the assembly of cells, thereby short circuiting the cells.

The glass-fiber separators can be strengthened with a backing, which must be conductive so that it will not increase the electrical resistance of the cell. The backing must be placed on the cathode side — anything other than lithium on the anode side would short circuit the cell. The backing on the cathode side must be either carbon or nickel, since the cathode is conductive carbon held by a nickel grid.

Both the nickel and the carbon backings appear to be viable. Because perforated nickel foil is already manufactured by electroforming, there should be no obstacle to the creation of a very thin, very porous nickel foil to serve as backing: Thicknesses of 20 μm with porosities above 50 percent are practicable.

Alternatively, conductive paper and cloth made of carbon fiber is available and could have the advantage of presenting more surface area for solvent reduction than the perforated nickel foil. The backing can be attached to the separator by polyisobutylene, a material resistant to sulfur, sulfur compounds, and oxidants (including ozone) up to at least 100 °C. The polyisobutylene is expected to dissolve completely in the thionyl chloride electrolyte solvent after the cell has been assembled; the adhesive is no longer needed after the cell is assembled.

This work was done by Eugene R. du Fresne of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 19 on the TSP Request card.*
NPO-16619

Material for Fast Cutting

Silicon nitride-based tool boosts productivity and reduces costs.

Marshall Space Flight Center, Alabama

A new material for cutting tools increases the productivity of machining processes. The material, called Iscanite (or equivalent), is based on silicon nitride and contains more than 90 percent silicon. It combines impact resistance close to that of coated carbides with heat and wear resistance close to those of aluminum oxide ceramics.

Tools made of Iscanite (or equivalent) can operate at higher cutting speeds. For equal pressure on the workpiece, an Iscanite (or equivalent) tool will therefore remove more material than will a conventional tool. The new material makes it unnecessary to use high pressure to increase the removal rate and therefore greatly reduces workpiece slippage, vibration, and tool breakage. Iscanite (or equivalent) tools last longer and therefore reduce the amount of cutting time lost to indexing, gauging, and adjustments.

The material is made by a hot-pressing technique that yields a product having full density. The material can be used for cutting on old or new machine tools and makes it possible to exploit fully the power and speed of a machine.

This work was done by Andrew Perez of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29130

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Effects of Radiation on Coatings

Tests help to insure reliability in a hostile environment.

Tests of radiation damage to materials used in the outer coverings of spacecraft are described in a 25-page report. The materials were exposed to ionizing radiation then examined for the degradation of desirable mechanical, electrical, and optical properties. Some of the experimental results and test methods may be applicable to aircraft, scientific instrumentation, and other equipment subject to ionizing radiation, electrostatic discharge, or both.

Electrically conductive tapes for preventing static-charge buildup were examined for decreases in peel and ultimate tensile strengths. The tests were performed on tapes with aluminum and copper coatings. The electrical grounding capability of the copper tape is superior to that of aluminum tape, but the aluminum tape retained more of its original mechanical strength after irradiation with electrons.

Two types of thermal blankets were exposed to a flux of energetic protons to match the environment expected in the vicinity of Jupiter. Both types of blanket included about 15 layers of ¼-mil (0.006-mm) polyethylene terephthalate. One type had a front-surface layer of 1-mil (0.025-mm) polytetrafluoroethylene filled with glass fibers and carbon, while the other had a surface layer of 1.5-mil (0.038-mm) polyester over 0.5-mil (0.013-mm) polyimide. The first type showed more erosion of the front layer than did the second type (16.3 percent versus 1.8 percent by weight).

Paints and other coatings for temperature control are listed with some of their mechanical, electrical, and thermooptical properties. The list includes both unfilled and carbon- or graphite-filled organic coatings (silicone, polyurethane, epoxy, fluorocarbon, and polyester) and inorganic coatings (silicate, titanate, ferric titanate, and zinc orthotitanate). The effects of radiation differ among the various coatings and include graying, increase in reflectance, weight loss, surface erosion, and loss of surface conductivity.

The report also describes standardized procedures and equipment for measuring the bulk and surface electrical resistivities of coatings. While the basic techniques of resistivity measurement are simple and well known, these test specifications are useful in coping with the peculiarities of coatings; in particular, by reducing environmental variations in the samples and insuring complete contact between electrodes and samples.

This work was done by Frank L. Bouquet, Victor F. Hribar, and Edward C. Metzler of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 111 on the TSP Request Card*
NPO-16533

Tests of Solar-Array Encapsulants

Materials were tested for degradation by heat and light.

A report presents early results of a continuing series of photothermal aging tests of some candidate encapsulating materials for solar photovoltaic modules. The objectives of the testing program are to contribute to the development of durable, low-cost encapsulants and to predict the lifetimes of encapsulated photovol-

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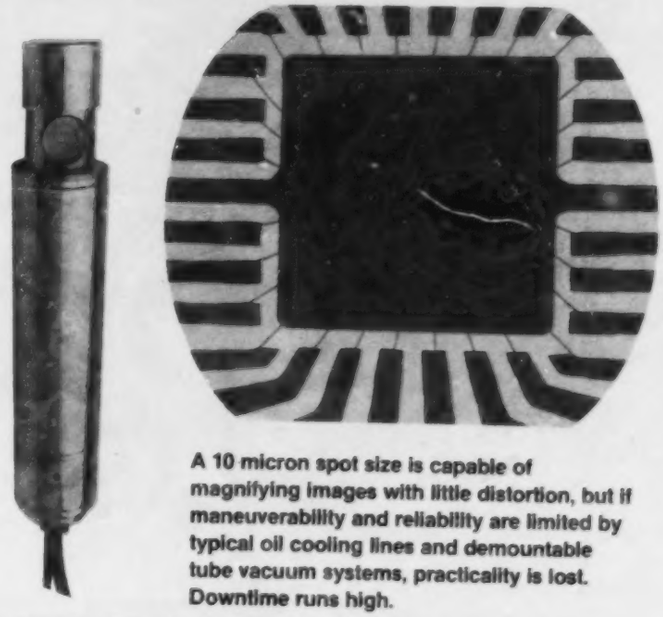

A 10 micron spot size is capable of magnifying images with little distortion, but if maneuverability and reliability are limited by typical oil cooling lines and demountable tube vacuum systems, practicality is lost. Downtime runs high.

Kevex' solution to the industry-wide problem was to develop a hermetically sealed x-ray tube more adaptable to the Quality Controller's environment and specifications.

The new KM10005S x-ray tube is air cooled and rated to 125 kV. The unique design and construction promises low maintenance, high performance, and a low cost.

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taic modules placed outdoors. Toward these ends, the tests are designed to reveal physical and chemical degradation mechanisms that affect the encapsulants.

The potting materials tested include ethylene vinyl acetate copolymer, polyvinyl butyral, room-temperature-vulcanizing silicone rubber, ethylene methyl acrylate copolymer, poly-n-butyl acrylate, and two aliphatic polyurethanes. Also tested were some acrylics and fluorocarbons that are likely to be used as outer-cover film materials.

Samples of these materials were aged at 55°, 70°, 85°, 105°, and 135° C. Control samples were aged in the dark while photothermal samples were exposed to ultraviolet radiation from a mercury lamp. Some specimens were mounted between glass covers to limit the access of oxygen, while others were exposed to the air.

Changes in several material properties were observed in the aged samples. These included the following:

- Optical transmittance was measured in the wavelength range of 300 to 1,200 nm. This helps quantify chemical changes involving the formation of oxidized species, indicated the component of diminution of photovoltaic performance due to the loss of transmittance, and gave a measure of the ultraviolet-screening ability of outer-cover films.
- Weight loss was measured to determine the loss due to evaporation of plasticizers, leaching of additives, and formation of volatile degradation products. Weight-loss measurements correlate with the formation of voids, which may cause delamination and corrosion.
- The uniaxial stress/strain response was measured to develop engineering modulus data and information on the stress-relaxation or creep behavior of the materials.
- For partially cross-linked polymers, solvent swelling and sol/gel ratios yield information on the network cross-link density and shape, which are critical structural parameters that control physical and chemical properties. Aging causes changes in these parameters; consequently, changes in swelling and sol/gel ratios are important measures of the outdoor stability of polymers.

This work was done by Ranty H. Liang, Keri L. Oda, Shirley Y. Chung, Mark V. Smith, and Amitava Gupta of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-172989 [N83-33339/NSP], "Handbook of Photothermal Test Data on Encapsulant Materials" [$16]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
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72 **Circle Reader Action No. 391**

Separation in Binary Alloys

Studies of monotectic alloys and alloy analogs are reviewed.

A report surveys research on liquid/liquid and solid/liquid separation in binary monotectic alloys. The report emphasizes separation processes in low gravity, such as in outer space or in free fall in drop towers.

Monotectic alloys are characterized by temperature/composition regions in which the liquid phases are immiscible. In normal Earth gravity, the droplets of the minority phase do not remain dispersed uniformly in the majority phase. Instead, because their density is usually different from that of the majority phase, the droplets rise to the top or fall to the bottom of the melt. Only in nearly zero gravity can the dispersed droplets be frozen in place during solidification — hence the interest in low-gravity research on these promising alloys.

The report first reviews early experiments, including drop-tube work on bismuth and gallium, rocket flights with

aluminum/indium, and orbital missions with oil/water mixtures on Skylab and zinc/lead on Apollo-Soyuz. The results of these experiments prompted researchers to look more seriously at phase-separation mechanisms, especially droplet migration in thermal gradients. If interfacial tension decreases with increasing temperature, as it does in most materials, the droplets of the minority phase will drift in the direction of the thermal gradient. The report describes thermal-migration experiments with transparent solutions.

The report takes up the critical-point wetting phenomenon and its role in phase separation and solidification. Advances in methods of controlling separation in experiments are highlighted.

A major difficulty in studying metal monotectic systems is that most of the information must be gleaned from the final solidified products. As a result, much effort over the past several years has been devoted to developing transparent analogous systems for studying phase separation. The report surveys this work. It considers holographic techniques for investigating spinodal decomposition in transparent systems. It also considers directional-solidification experiments with succinonitrile in water, a mixture that is not only transparent but also solidifies at convenient temperatures (around 20°C).

This work was done by Donald O. Frazier, Barbara R. Facemire, William F. Kaukler, William K. Witherow, and Ursula Fanning of **Marshall Space Flight Center.** *Further information may be found in NASA TM-82579 [N84-24773/NSP], "Separation Processes During Binary Monotectic Alloy Production" [$8.50]. A paper copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 92 on the TSP Request Card.*
MFS-27074

Crack Growth in Single-Crystal Silicon

Experimental results suggest an absence of subcritical crack growth.

A report describes experiments on crack growth in single-crystal silicon at room temperature in air. These results could aid in the design and fabrication of silicon photovoltaic and microelectronic devices.

Crack growth in the {111} cleavage plane of wafers, 50 by 100 by 0.76 mm in dimension, cut from Czochralski single-crystal silicon was studied by the double-torsion load-relaxation method and by acoustic-emission measurements. Scanning electron microscopy and X-ray topography were also employed.

The findings include the following:

- The critical stress-intensity factor for cleavage-crack propagation in the {111} cleavage plane of single-crystal silicon was 1 $MN/m^{-3/2}$ by the double-torsion load-relaxation method. At the critical stress-intensity factor, cracks propagated by jumping.
- No load relaxation was observed during the load-holding period of the double-torsion test; hence, there was no measurable, slow-moving crack growth. This suggests the absence of subcritical crack growth.
- During loading, no acoustic-emission event was detected before the critical-stress-intensity factor was reached or during the load-relaxation-holding period. This observation also suggests the absence of subcritical crack growth.
- Acoustic-emission peak amplitudes with a signal-to-noise ratio greater than 60 dB were found at the critical stress-intensity factor for cleavage-crack propagation in the {111} plane of single-crystal silicon.
- Examinations of fracture surfaces revealed that during crack growth, the typical crack front jumped several times in a "mirror" region (where the crack surface was relatively smooth), before it propagated rapidly in a "hackle" region (where the surface was rough).
- Hackle marks on the fracture surface were associated with arrays of dislocation etch pits. Hackle marks appear to result from plastic deformation at the tips of rapidly moving cracks.
- Dislocation etch pits were not observed on the crack-front markings or in the flat areas of the "mirror" surfaces. In the mirror region, crack growth may result from interatomic bond breakage at the crack tip.
- Acoustic emission appears to be generated spontaneously from crack-front jumping (interatomic bonds broken) and hackle-mark formation (dislocation generation) during the crack growth.

This work was done by Chern P. Chen and Martin H. Leipold of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Crack Growth in Single-Crystal Silicon," Circle 106 on the TSP Request Card.*
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Computer Programs

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For additional information on any programs described in this issue of *Tech Briefs*, circle the appropriate number on the TSP card at the back of the publication. If you don't find a program in this issue that meets your needs, you can call COSMIC directly at (404) 542-3265 and request a review of programs in your area of interest. There is no charge for this information review.

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Electronic Systems

Economic-Analysis Program for a Communication System

Prices and profits of alternative designs can be compared.

The objective of the Land Mobile Satellite Service Finance Report (LMSS) program is to provide a means for comparing alternative designs of LMSS systems. This program is actually a Multiplan worksheet program. The labels used in the worksheet were chosen for a satellite-based cellular communication service, but the analysis is not restricted to such cases.

A comprehensive financial model is used to calculate a figure of merit, which can be used to compare effects of equipment and operating costs, pricing strategy, and customer demand for different systems. The program also calculates the price that a company would have to charge customers to meet all its expenses and make a specified profit. A price estimate can be obtained for almost any service that is heavily dependent on capital investment and which has operating costs that depend on the amount of service sold.

The economic analysis has two main components: supplier finances and customer finances. Supplier finances include amortization, interest, insurance, taxes, and operating and maintenance expenses. Customer finances include usage rate, subscription fees, equipment costs, and estimated traffic. Prices can be defined as real or nominal to account for the effects of escalation and inflation, and the profits can be regulated or unrestricted.

LMSS is written for interactive execution with Multiplan (version 1.2) and has been implemented on an IBM PC series computer operating under DOS (version 2.11). The LMSS worksheet program has a space requirement of approximately 38K of 8-bit bytes. This worksheet program was developed in 1984.

This program was written by R. G. Chamberlain of **NASA's Jet Propulsion Laboratory.** *For further information, Circle 88 on the TSP Request Card.*
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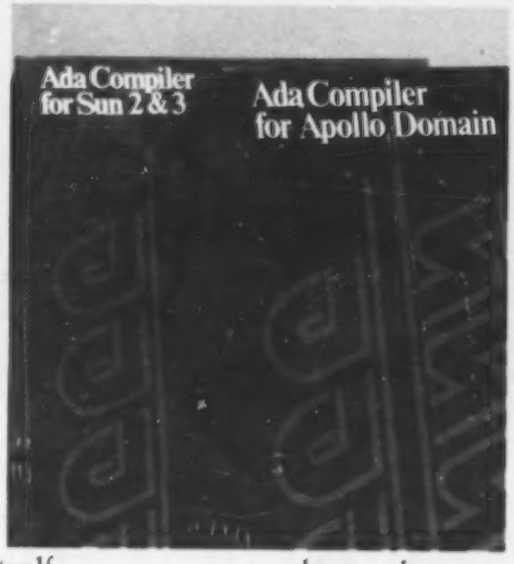

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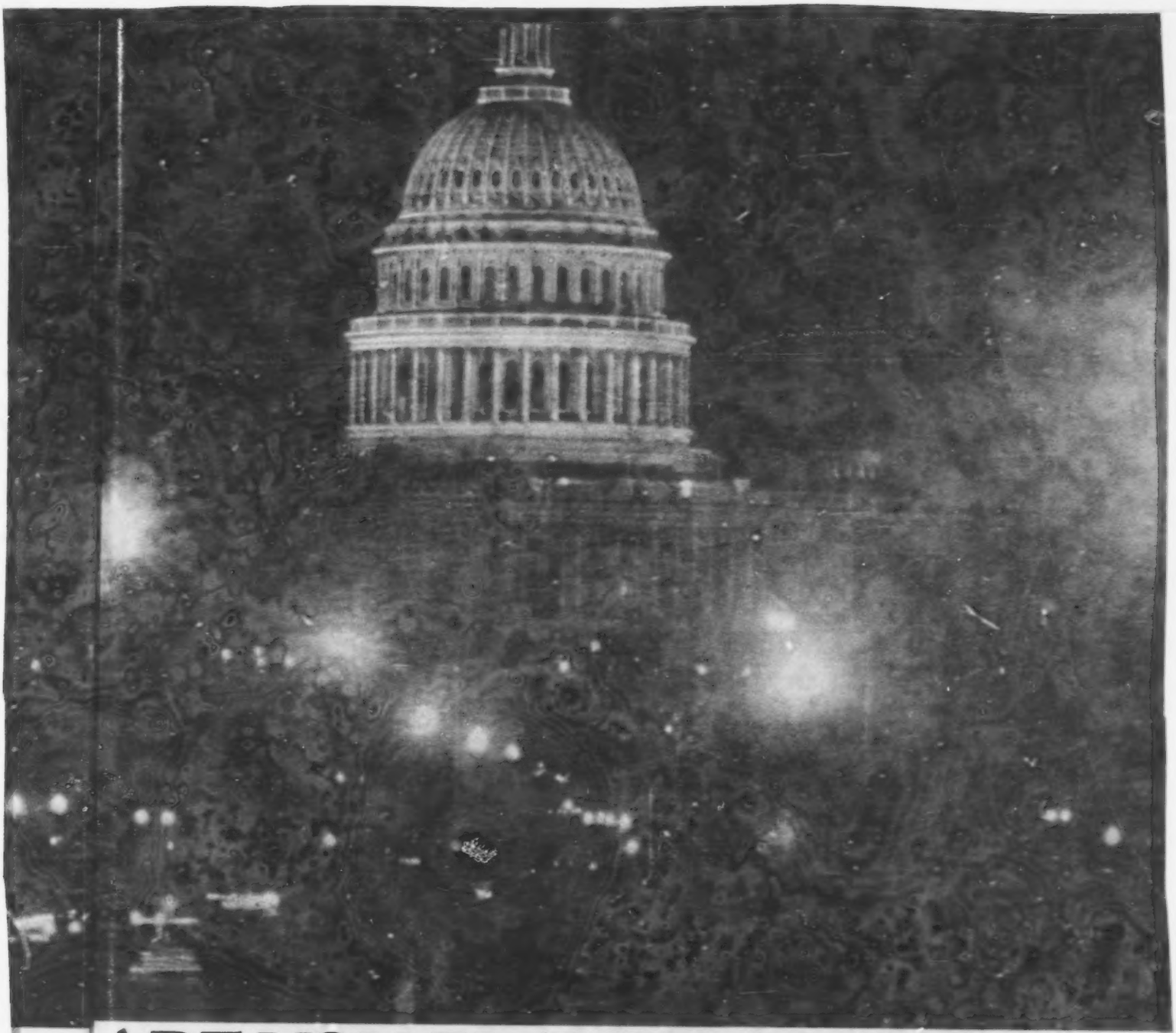

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Circle Reader Action No. 353

Physical Sciences

Predicting the Cosmic-Ray Environment Near Earth

The rates of logic-circuit bit errors are estimated.

This package of computer programs was developed to predict the cosmic-ray environment for a spacecraft in orbit near Earth. A single cosmic-ray particle can deposit enough electrical charge on a sensitive area of an individual circuit to change the bit state. These single-event upsets may not cause permanent damage but can upset functioning devices. This package has been used to predict the upset rate for a space mission. The package can also calculate the time-average cosmic-ray environment for multiple circular orbits, fragments of trajectories, and isolated points.

A simple transport analysis is used to approximate the environment at the center of a spherical shield of arbitrary thickness. The effects of mass shielding and magnetic shielding are included in the computation. The principle output of the package is a Heinrich curve describing the flux of cosmic-ray particles with a given linear energy transfer (LET).

The package contains five programs: (1) GEOMAG calculates the modulating factor due to geomagnetic shielding for a given trajectory segment; (2) SPECTRUM calculates interplanetary cosmic-ray spectra and uses the GEOMAG factor to produce a time-average spectrum at the spacecraft exterior; (3) INTEGRATE converts differential spectra to integral spectra; (4) TRANSPORT computes the integral flux at the center of a spherical, shielded region; and (5) UPSET FLUX calculates the flux that causes an upset for each threshold LET. The programs are normally run in succession, but each can be used in a stand-alone fashion if the necessary input is available from outside sources.

This package is written in HPL for interactive execution and has been implemented on an HP 9825B desktop computer. This package was developed in 1985.

This program was written by L. D. Edmonds of **NASA's Jet Propulsion Laboratory.** *For further information, Circle 78 on the TSP Request Card.*
NPO-16617

Mechanics

Predicting Aircraft Spray Patterns on Crops

A computer program examines how aircraft designs affect the deposition of agricultural materials.

The Agricultural Dispersion Prediction (AGDISP) system was developed to predict the deposition of agricultural material released from rotary- and fixed-wing aircraft. AGDISP computes the ensemble average mean motion resulting from turbulent fluid fluctuations.

The development of the AGDISP system was motivated by the need to determine how aircraft-unique wake and propulsion-system characteristics affect the ground deposition of aerially released material. Simple aircraft-design changes, such as winglets, could potentially produce a more-desirable deposition pattern. AGDISP can be used to examine ways of making the dispersal process more efficient by insuring uniformity, reducing waste, and saving money.

AGDISP assumes that the particles are influenced by three forces: (1) aerodynamic drag, (2) forces as a consequence of evaporation, and (3) gravity. A Lagrangian approach was used to develop the equations of motion of discrete particles released from an aircraft. A predictor/corrector solution scheme is used to solve the resulting set of ordinary differential equations. The behavior of the particles is intimately connected to the local background mean-velocity and turbulence fields through which the particles are transported.

Flow-field options available in AGDISP include fixed-wing fully-rolled-up tip vortexes; fixed-wing Betz rollup, propeller, helicopter in forward advance; mean-background crosswind, plant canopy, superequilibrium turbulence, terrain; and externally-computed mean-velocity and turbulence fields. The particle equations are integrated repeatedly until either the specified maximum simulation time is reached or all of the particles deposit on the surface.

The AGDISP system consists of three computer programs: The AGDISP program establishes the desired background fields and computes the particle trajectories. The AGPLOT program plots the resulting trajectories and deposition pattern. The AGLINE program constructs an equivalent Gaussian-profile distribution from the multiparticle solution. Each of the programs is designed to run interactively, with the AGPLOT program supporting a Tektronix terminal with PLOT 10 software.

The programs in the AGDISP system are written in FORTRAN IV for interactive execution and have been implemented on a CDC CYBER 170-series computer operating under NOS 1.4 with a central-memory requirement of approximately 60K total of 60-bit words. The AGDISP system was developed in 1984.

This program was written by Milton E. Teske and Alan J. Bilanin of Continuum Dynamics, Inc., for **Langley Research Center.** *For further information, Circle 63 on the TSP Request Card.*
LAR-13432

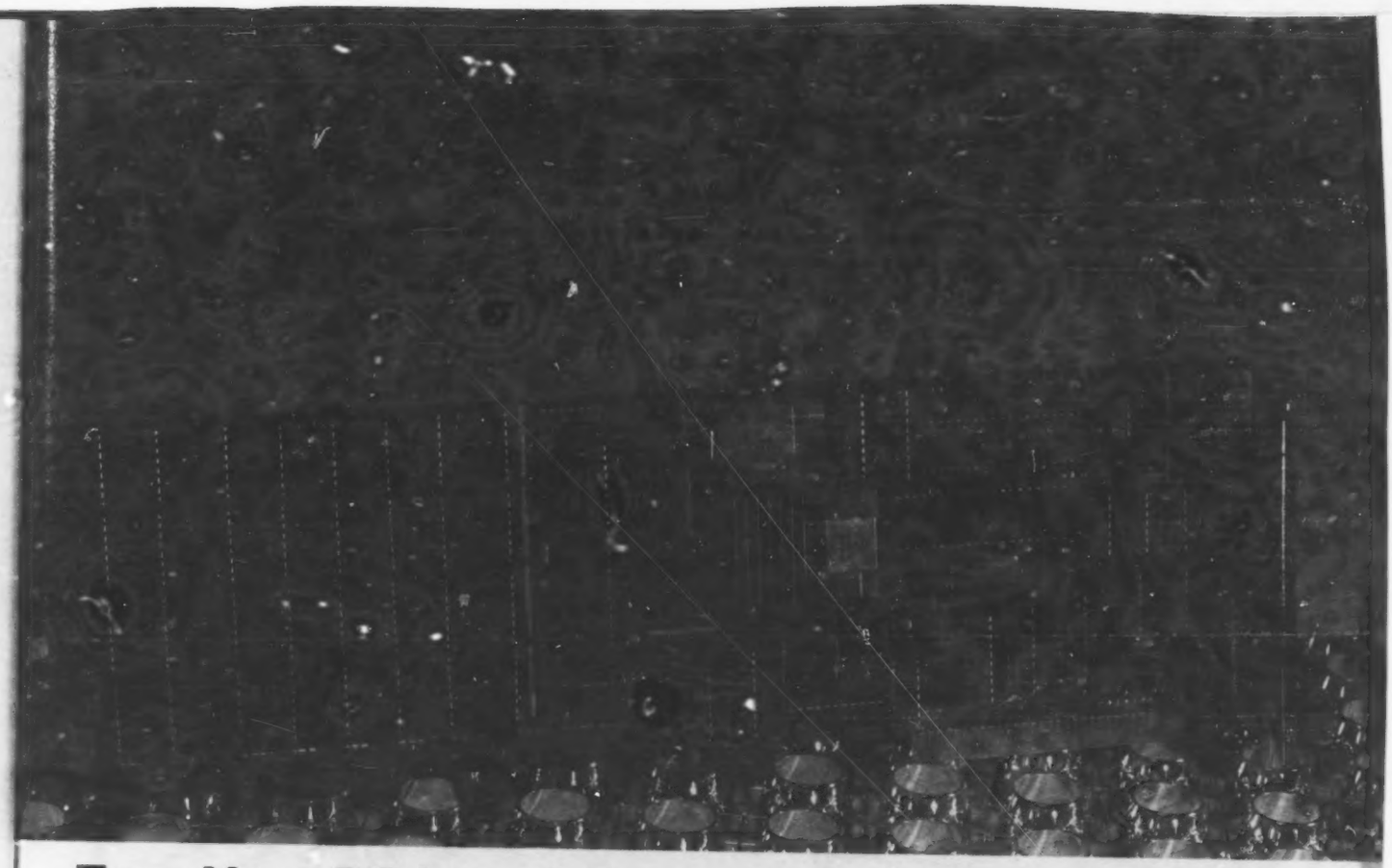
Estimating Average Wind Velocity Along a Trajectory

The variation of wind velocity with altitude is taken into account.

The Average Wind Velocity (VWAVE) program calculates the average wind velocity over time for a particular vehicle trajectory. The calculation is based on wind profile, which is the wind magnitude at various altitudes. The average of a wind profile over altitude does not correlate well with the actual apparent effect of wind. Wind profiles with low average velocities may be more severe than some wind profiles with high average velocities.

The amount of time a vehicle experiences each different wind level of a profile is taken into account by VWAVE. The VWAVE program produces a reliable description of the relative magnitude of wind profiles as experienced by a certain trajectory. VWAVE was developed for use in analyzing the Space Shuttle orbiter glide return to the ground, but is useful for wind effects on takeoff and landing trajectories of other aircraft, as well as performance evaluations and dispersion theory.

There are two methods of calculation: In the first, the user must enter a wind profile and the vertical velocity versus altitude. This can be done interactively with the provided elementary editor. The second method requires wind-profile-versus-time data from a trajectory simulation in the standard TRWPLT format. The VWAVE program is menu driven and has options to list or edit the input files. The final result is a calculated value of wind velocity, which, if held constant, would approximate the same effects as those of the given wind profile on that particular trajectory.



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Float Benchmark					
40,000	11.46	17.71	.83	.50	.80

Unix Benchmarks

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VWAVE is written in FORTRAN V for interactive execution and has been implemented on a UNIVAC 1100-series computer with a central-memory requirement of approximately 21K of 36-bit words. The program was developed in 1981.

This program was written by Paul Bertsch of McDonnell Douglas Corp. for **Johnson Space Center.** *For further information, Circle 64 on the TSP Request Card.*
MSC-20792

Research Program for Vibration Control in Structures

Compensating algorithms are developed from optimal-control theory.

The purpose of this research computer program is to apply control theory to large space structures (LSS's) and to design a practical compensator for suppressing vibration. LSS's often have rigid hubs or flexible struts or ribs and may have meshed surfaces. These elements produce rigid-body modes and flexible vibration modes with closely-packed structural frequencies. This program models the LSS as a distributed system. Control theory is applied to produce a compensator described by functional gains and transfer functions. This program has been used for the comparison of the robustness of low- and high-order compensators that control the surface vibrations of a realistic wrap-rib antenna.

Distributed-system theory and finite-dimensional control theory are combined by use of approximations. The ideal, or optimal, compensator for a distributed system is infinite-dimensional. This program approximates the infinite-dimensional compensator by the use of finite-dimensional linear/quadratic Gaussian optimal-control equations. Balanced realizations are used to reduce the order. The LSS itself is mathematically described as a Galerkin/component-mode finite-element model.

The program is written in FORTRAN for batch execution and has been implemented on an IBM 30xx series computer. The program was developed in 1984.

This program was written by D. L. Mingori and J. S. Gibson of H. R. Textron, Inc., for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 42 on the TSP Request Card.*
NPO-16615

Flutter and Vibration Animation Program

Vibration analyses of machines and structures are converted to animated displays.

The Flutter and Vibration Animation (FLUVIAN) program produces an animated picture of a structure as it vibrates at constant amplitude. FLUVIAN permits visual observation of the fluttering motion of components as they oscillate in a combination of modes. The animated display provides an insight into local deflection patterns induced in the structure, which might be overlooked if the modal deflection patterns were separately examined and then combined mentally.

FLUVIAN uses the segment and refresh features of the Tektronix 4114 computer-graphics terminal. Each time-step picture of an oscillating structure is defined as a segment. The segments are turned on and off sequentially to produce an animated display of the motion.

The input data to FLUVIAN may consist of up to 2,000 lines per plot, with lines denoted by coordinates of the end points. The sample data provided with FLUVIAN are from the analysis of the Space Shuttle orbiter fin flutter. FLUVIAN is also applicable to motion studies of buildings, bridges, oil rigs, moving parts of automobiles, and other complex structures.

The FLUVIAN program is written in FORTRAN 77 for interactive execution and has been implemented on a CDC CYBER 170-series computer operating under NOS with a central-memory requirement of approximately 56,300 (octal) of 60-bit words. This program requires the PLOT-10 Terminal Control System and a Tektronix 4114 graphics terminal. FLUVIAN was developed in 1984.

This program was written by Richard L. Tischner of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 60 on the TSP Request Card.*
MSC-20895

Combining Structural and Substructural Mathematical Models

Automation reduces input length and potential data-entry errors.

The Matrix Automated Reduction and Coupling (MARC) program is used for combining NASTRAN® substructural models with a primary structural model. MARC also constructs the job-control language (JCL) stream for a NASTRAN batch job that utilizes a previously-written user library of dynamic models. This automation minimizes lengthy input and reduces potential data-entry errors. The MARC procedure has been used in assembling the Space Shuttle orbiter dynamic models since 1983 and has reduced NASTRAN modeling input time by as much as 50 percent.

MARC uses the NASTRAN Substructure Operating File (SOF) to assemble mathematical models, then reduces the stiffness and mass matrices of the substructure assemblies. The reduced matrices are then coupled to the primary structural model. Optionally, MARC adjusts the primary structure mass matrix via NASTRAN Direct Matrix Input.

Before using MARC to assemble a model, the user must create a data base containing the following information: (a) grid coordinates and data for generating the NASTRAN BDYS1 map, (b) up to 50 substructure-identification codes and the corresponding SOF names, and (c) stiffness and mass matrices for the primary structure and substructures. MARC generates map files, tape backups of substructure matrices, and the JCL stream for a batch NASTRAN job to assemble the final dynamic model.

The MARC program is written in FORTRAN IV for interactive execution and has been implemented on an IBM 370-series computer operating under OS/VS2 with a central-memory requirement of approximately 55K of 8-bit bytes. MARC was developed in 1982.

This program was written by Victor K. Choa of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 28 on the TSP Request Card.*
MSC-20897

Analyzing Shuttle Orbiter Trajectories

Measurements are combined to produce best estimates of flight paths.

The LRBET4 program is a best-estimate-of-trajectory (BET) calculation for post-flight trajectory analysis of the Shuttle orbiter. LRBET4 produces estimated measurements for comparing the predicted and actual trajectory of an Earth-orbiting spacecraft. A Kalman filter and a smoothing filter are applied to the input data to estimate the state vector, reduce noise, and produce the BET.

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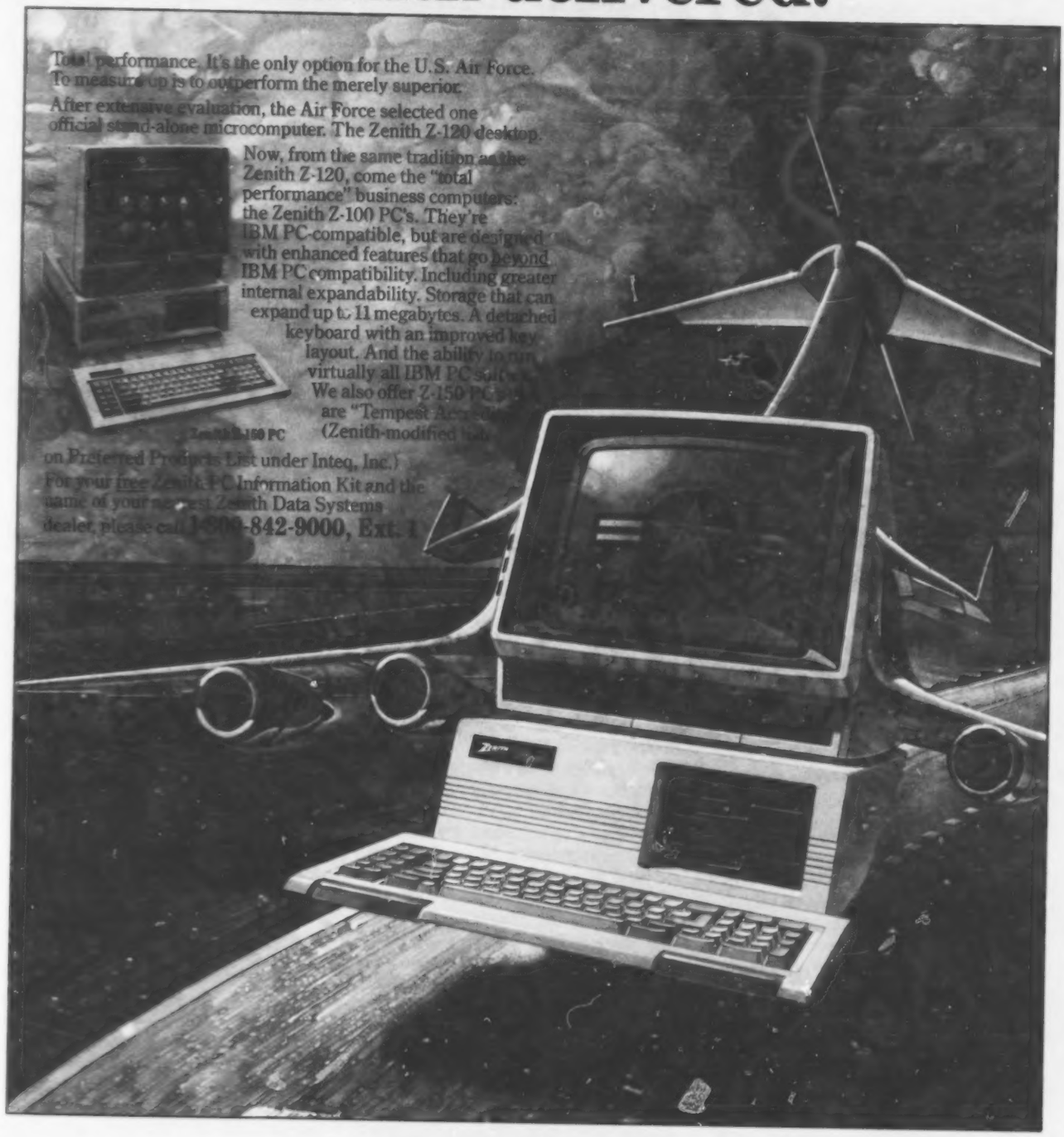
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taneous range measurements from tactical air navigation sites, C-band radar, and S-band radar. In addition, LRBET4 accepts Doppler measurements obtained from tracking data-relay satellites. Inertial-measurement-unit data are used in the equations of motion to improve accuracy during large burns.

The program incorporates a Kalman filter to process all navigational data prior to a given time. This output is then used by a backward-smoothing filter to estimate the state vector based on data before and after the given time. The normal LRBET4 output is the state vector from the smoothing filter. Abbreviated runs can be performed using only the forward Kalman filter. The state vector is propagated at time intervals of less than 60 seconds, with its output to a magnetic tape or a printer.

LRBET4 is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of approximately 117K (octal) of 60-bit words. The program was written in 1983.

This program was written by William M. Lear of TRW, Inc., for **Johnson Space Center.** *For further information, Circle 61 on the TSP Request Card.*
MSC-20786

Predicting Failures of Composite, Spherical Pressure Vessels

Long-term viscoelastic effects are computed to predict bursts.

Spherical pressure vessels are commonly made of filamentary composites for applications in which they must be light in weight. This program was developed for predicting the failure of such a vessel over a long time span. Short-term failure pressures (bursting points) can be predicted, but the long-term structural integrity of laminated vessels is being studied only now.

This program examines the time-dependent response of a vessel by considering the linearly viscoelastic character of the matrix, which binds high-strength fibers wrapped around an inner metallic liner. Under conditions of sustained high pressurization, the burst pressures and critical strains on composite pressure vessels are shown to vary with time. A laminated Kevlar (or equivalent aromatic polyamid) resin model is evaluated, and the filament volume ratio is found to be a significant factor in long-term performance.

The spherical vessel is modeled as a pseudoisotropic composite shell. By use of the maximum-strain theory of failure, both the burst pressure and the critical-strain equations are formulated, solved in the Laplace domain, and inverted to the time domain by the method of collocation. The required inputs include the elastic modulus, Poisson's ratio, shell diameters, loads, initial strains, and volumes. An auxiliary program is included for the calculation of initial burst pressures and strains.

These programs are written in FORTRAN 77 for batch execution and have been implemented on a UNIVAC 1100-series computer with a central-memory requirement of approximately 7K of 36-bit words. The programs were developed in 1983.

These programs were written by Jan D. Dozier of **Marshall Space Flight Center.** *For further information, Circle 62 in the TSP Request Card.*
MFS-27050

Machinery

HYTESS-Hypothetical Turbofan-Engine Simplified Simulation

Simulated characteristics mimic those of advanced turbofan engines.

A computer program has been developed to offer those interested in engine dynamics and controls research an efficient, realistic, and easily-used engine simulation. This simulation was developed from linearized operating-point models but still retains essential nonlinear engine effects. The simulation is representative of a hypothetical, low-bypass-ratio, twin-spool, axial-flow turbofan engine.

Typically, turbine-engine simulations incorporate detailed nonlinear descriptions of both steady-state and dynamic engine operation through the engine flight envelope. These detailed nonlinear simulations are very accurate and realistic and, when implemented in a digital computer, require relatively large amounts of computer storage and computer-processing time. This makes these detailed simulations difficult and costly to use. HYTESS was developed as an alternative. It is structurally simpler than a full nonlinear engine simulation and therefore has reduced storage and processing requirements.

HYTESS retains the essential nonlinear effects inherent in the engine operation. This is accomplished by modeling the engine using a linear state-space formulation and incorporating the nonlinear characteristics by representing the matrix elements within the linear state-space structure as nonlinear functions of various engine variables. The compromise implied in this process is that, although the fidelity of HYTESS is maintained for the variables considered, it is very difficult to identify individual component behavior as in a detailed simulation. Also HYTESS is restricted to operating in regions about the normal operating line of the engine.

The engine characteristics simulated by HYTESS, although hypothetical, are qualitatively similar to those of realistic advanced turbofan engines. Typical applications for this simulation would include open-loop engine dynamics studies as well as closed-loop controls analysis using a user-generated control law.

This program is written in FORTRAN IV for use on an IBM 3033 AP computer running under the TSS/370 operating system.

This program was written by W. C. Merrill of **Lewis Research Center,** *C. Beattie and R. F. LaPrad of Pratt & Whitney Aircraft Co., and S. M. Rock and M. M. Akhter of Systems Control Technology, Inc. For further information, Circle 22 on the TSP Request Card.*
LEW-14020

Aircraft Rollout Iterative Energy Simulation

A computer program evaluates the performance of aircraft brakes.

The Aircraft Rollout Iterative Energy Simulation (ARIES) program analyzes aircraft-brake performance during rollout. The program simulates a three-degree-of-freedom rollout after nose-gear touchdown. The amount of brake energy dissipated during the aircraft landing determines the life expectancy of brake pads. ARIES incorporates brake pressure, actual flight data, crosswinds, and runway characteristics to calculate the following: (a) brake energy during rollout for up to four independent brake systems; (b) time profiles of rollout distance, velocity, deceleration, and lateral runway position; and (c) all aerodynamic moments on the aircraft.

ARIES can be adapted for modeling most landing aircraft during unpowered rollout. Optimum braking procedures can be developed with ARIES to minimize brake deterioration within the specified lengths of runway. ARIES has been used to evaluate several Space Shuttle orbiter brake-pad failures.

After the input of initial runway and

landing conditions, ARIES utilizes three simulation models to evaluate the rollout at given time intervals. The brake-force simulation requires tire and brake information along with actual flight data. The equations of motion allow force and moment balances to be calculated. The aerodynamic effects are computed, including lift, drag, axial and normal forces, and roll, pitch, and yaw moments. The various aerosurface effects are obtained from interpolation of the Rockwell Aero Sciences Group Design Data Book tables. The output is in both printed and plotted forms. ARIES iterates the calculations until the computed forward velocity is below 3 knots (1.5 m/s).

ARIES is written in FORTRAN 77 for batch execution (interactive usage is possible, but high external-core memory requirements may limit its practice) and has been implemented on a CDC CYBER 170-series computer with a central-memory requirement of 64K of 60-bit words, with up to an additional 460K of 60-bit words for storing the aerodynamic-coefficient table interpolation subroutines. ARIES was developed in 1984.

This program was written by Lane Kinoshita of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 65 on the TSP Request Card.*
MSC-20816

Estimating Transient Pressure Surges in Cryogenic Systems

Potentially-damaging pressure waves can be anticipated and, therefore, avoided.

A mathematical model has been developed for the prediction of pressure behavior in single- and two-phase cryogenic systems. A transient-liquid-flow analysis has been modified to incorporate the behavior of vapor bubbles and is used to predict maximum pressure in cryogenic transfer systems consisting of complex pipe and valve arrangements under both steady-state and transient conditions. This simulation has compared favorably with data obtained during the transfer of liquid oxygen from ground storage tanks to the Space Shuttle orbiter external tanks.

Within a cryogenic liquid-transfer system, vapor cavities can easily be formed if a localized reduction in pressure occurs. Any valve opening or closing may cause the cavities to form or collapse due to a pressure variation. The collapse of an entrapped vapor cavity causes a water hammer-type effect and the creation of high-pressure waves, which may damage the piping system and associated instrumentation. To predict the magnitude of undesirable pressure surges, this model uses the method of characteristics and basic fluid-mechanics equations, taking into account vapor cavities. The program output includes maximum pressure at junctions, the pressure head and velocity at the upstream and downstream ends, and the length of any vapor cavities in the piping system.

This program is written in FORTRAN 77 for batch execution and has been implemented on a DEC VAX-series computer with a central-memory requirement of approximately 105K of 8-bit bytes. The program was developed in 1983.

This program was written by Phillipe Pfister, F. S. Gunnerson, and E. R. Hosler of the University of Central Florida for **Kennedy Space Center.** *For further information, Circle 87 on the TSP Request Card.*
KSC-11312

Computing Cooling Flows in Turbines

The required flow and the consequent decrease in efficiency are predicted.

An algorithm has been developed for calculating both the quantity of compressor bleed flow required to cool a turbine and the resulting decrease in efficiency due to cooling air injected into the gas stream. Because of the trend toward higher turbine-inlet temperatures, it is important to predict accurately the required cooling flow. This program is intended for use with axial-flow, air-breathing, jet-propulsion engines with a variety of airfoil-cooling configurations. The algorithm results have compared extremely well with figures given by major engine manufacturers for given bulk-metal temperatures and cooling configurations.

The program calculates the required cooling flow and corresponding decrease in stage efficiency for each row of airfoils throughout the turbine. These values are combined with the thermodynamic efficiency of the uncooled turbine to predict the total bleed airflow required and the altered turbine efficiency. There are 10 airfoil-cooling configurations, and the algorithm allows a different option for each row of cooled airfoils. Materials technology is incorporated and requires the date of the first year of service for the turbine stator vane and rotor blade. The user must specify pressures, temperatures, and gas flows into the turbine.

This program is written in FORTRAN IV for batch execution and has been implemented on an IBM 3080-series computer with a central-memory requirement of approximately 61K of 8-bit bytes. The program was developed in 1980.

This program was written by James Gauntner of **Lewis Research Center.** *For further information, Circle 23 on the TSP Request Card.*
LEW-13999

Four-Cylinder Stirling-Engine Computer Program

Both steady-state and transient simulations include realistic effects.

A computer program has been developed for simulating the steady-state and transient performance of a four-cylinder Stirling engine. Usual Stirling-engine models include only two pistons and the working space between them. For analysis, the working space is usually segmented into control volumes corresponding to engine components: expansion space, heater, regenerator, cooler, and compression space. More than one control volume may be used to describe each component. Also, various heat-transfer paths are included in the model. While many Stirling engines have more than one working space, the models used to predict performance generally do so for a single working space, and the resultant output power is multiplied by the number of working spaces. Although this approach is acceptable for performance calculations, it has shortcomings when the constant-pressure assumption cannot be used, such as when the amount of hydrogen within a working space varies during a cycle.

The new Stirling-engine computer model overcomes these difficulties. In the model, four cylinders are interconnected by four working spaces. Each working space contains seven volumes: one for the expansion space, heater, cooler, and compression space and three for the regenerator. A thermal time constant for the regenerator mass is associated with each regenerator gas volume.

The thermodynamic model includes both continuity and energy equations and simplified, first-order momentum terms (flow resistance). Drive dynamics and vehicle load effects are included. The computer program includes a model of a hydrogen-supply system to accelerate the engine.

The simulation can generate, at the user's option, steady-state or transient data. Steady-state power and torque predictions compare well with experimental data over a wide range of engine speeds and pressures. The model contains 70 state

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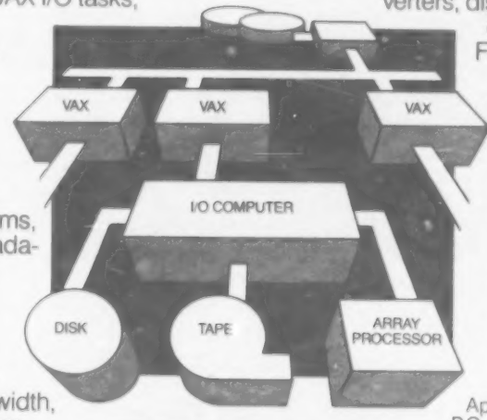

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variables. Also included in the model are piston-rod-seal leakage effects.

The simulation is modular to allow for easy modification of the model. An input routine is provided in which the user specifies the transient to be run and supplies the necessary engine geometry data. The type of output is also selected by the user. Very detailed printouts at prescribed intervals can be selected; alternatively, less detailed printouts can be selected. The integration step size and the printout interval do not have to be the same.

This computer code contains energy-equation effects and has many more volumes per working space than the previously published Stirling engine code, "Four-Cylinder Stirling Engine Control Simulation" (LEW-14106), page 148, *NASA Tech Briefs*, Vol. 9, No. 4. However, both codes give similar results and can be used together. The former code can generate results very quickly, since it has only 14 state variables with no energy equation. The current code can then be used to study various aspects of the Stirling engine in much more detail.

The program is written in FORTRAN IV for use on an IBM 370 computer.

This program was written by Carl J. Daniele and Carl F. Lorenzo of **Lewis Research Center.** *For further information, Circle 55 on the TSP Request Card.*
LEW-14155

Mathematics & Information Sciences

Graphics Programs for the DEC VAX Computer

A variety of plots is available in video or printed form.

This LONGLIB library of computer programs is a set of subroutines designed for vector plotting on cathode-ray tubes and dot-matrix printers. LONGLIB subroutines are invoked by program calls similar to standard CALCOMP routines. In addition to the basic plotting routines, LONGLIB contains an extensive set of routines to allow viewport clipping, extended character sets, graphic input, gray-level plots, polar plots, and three-dimensional plotting with or without the removal of hidden lines.

LONGLIB includes "master subroutines," which are self-contained series of commonly used individual subroutines. When invoked, the master routine initializes the plotting package; plots contours, histograms, multiple curves, scatter plots, log plots, three-dimensional plots, etc.; then closes the plot package; all with a single call.

LONGLIB was designed to produce plots on VT100's with Seinar boards, VT125's, VT240's, terminals compatible with the Tektronix 4010, and color RAMTEK 9400 devices. Printer output is available by using the raster-scan conversion routines for Printronix printers and high- or low-resolution Trilog printers. Software could easily be modified for other graphics output devices. The LONGLIB package includes the graphics library, an online help library, scan-converter programs, and command files for installing, creating, and testing the library.

LONGLIB is written in FORTRAN 77 and C (C language required for RAMTEK interface only) for batch execution and has been implemented on a DEC VAX series computer operating under VMS. These programs were developed in 1985.

This program was written by D. G. Long of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 84 on the TSP Request Card.*
NPO-16666

Computing Benefits and Costs for Propulsion Systems

A weight-criteria rating approach is followed.

A flexible computer model has been developed for evaluating the benefits and costs of placing large space systems into operational orbits. With the advent of an operational space transportation system (STS), NASA will have the capability of transporting large-volume/low-density payloads to low Earth orbit (LEO). Some of these will be structures that allow the placement of very large antennas (200-m diameter), or collections of communications systems, in orbits ranging from LEO to geosynchronous Earth orbit (GEO). Currently, one approach is to deploy these large space systems (LSS) in LEO and transfer them to their operational orbits by a primary propulsion system. The vehicle thrust must be limited to assure that loading during the final acceleration will not collapse the lightweight structure. It was necessary to determine the most beneficial and cost-effective thrust level for orbit transfer of these payloads.

When subjecting a primary propulsion system to mission catalog requirements, this analytical model calculates a mission capture rating, benefit value, RDT&E costs, production costs, and launch costs, in addition to life-cycle cost at various thrust levels. The benefit section of the model follows a weighted-criteria rating approach. Ten benefit criteria, such as mission capture, engine reliability, primary propulsion system (PPS) length, and technical risk, are available for the benefit-value calculation. Each benefit criterion is assigned a weighting for flexibility. Mission capture rating is a function of thrust level, the probability of mission occurrence, and the number of STS launches.

RDT&E and PPS costs are based on vehicle subsystem masses. Government and commercial STS launch costs are taken into account. The combination of these two algorithms resulted in a benefit-and-cost model, which iterates on thrust level such that the most cost-effective and beneficial thrust level is selected for a given mission catalog.

The model at present contains the performance envelopes of three primary propulsion systems for orbit transfer based on three low-thrust engines. The model allows for any mission model to be input into the program. The model also allows the user to easily vary the program to examine the effects of various ratings and the weighting of benefit parameters for the baseline engines.

This program is written in FORTRAN IV for use on an IBM 370 computer.

This program was written by K. M. Hamlyn, R. I. Robertson, and L. J. Rose of Martin Marietta Denver Aerospace for **Lewis Research Center.** *For further information, Circle 66 on the TSP Request Card. LEW-14129*

Analyzing Multidimensional Image Data

Six computer programs perform histogram cluster analysis.

The Histogram Cluster Analysis Procedure (HICAP) was developed to perform an unsupervised classification of multidimensional image data. The clustering approach used in HICAP is based on an algorithm described by Narendra and Goldberg, which uses a multidimensional histogram to perform an unsupervised classification of four-dimensional Landsat multispectral-scanner data. HICAP generalizes this procedure to process up to 32-bit data with an arbitrary number of dimensions. HICAP also incorporates efficiency improvements so that classification requires less computation than does the original algorithm. The computational savings afforded by HICAP increase with the number of dimensions in the data.

HICAP consists of a set of six computer programs that are executed in sequence. The first program, BHISTO,

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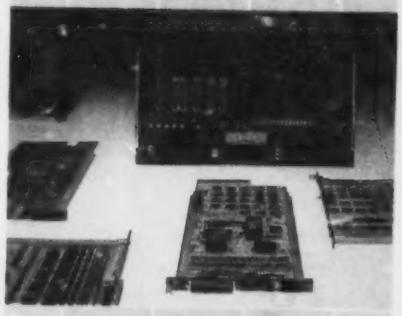

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takes an image data file and builds a multidimensional histogram consisting of the cell indices and the frequency of occurrence of the nonzero cells. Program BKTREE facilitates searching for cell neighbors in the histogram by reordering the raw histogram according to the K-d search trees.

Program CNSEARCH uses the reordered histogram and K-d search tree to locate cell neighbors in the histogram, producing a list of the cell neighbors and their respective separation distances. Program SMOOTH smooths the histogram by selectively averaging cells, replacing the frequency of occurrence of each cell by the average frequency of its neighbors as defined in the neighbor index list.

Program CLUSTER locates clusters in the histogram by locating local maximums in the frequency distribution estimate and using frequency gradients to determine the population of each cluster. Finally, the CLASSIFY program uses the clustered histogram to classify the original data by table lookup via hashing. Various utility programs are included to derive a spatial or spectral subset of an image, to print an image in integer format, and to print various files used by HICAP.

The HICAP programs are written in FORTRAN 77 for batch or interactive execution and have been implemented on a DEC VAX-series computer with the largest program having a memory requirement of approximately 740K of 8-bit bytes. HICAP was developed in 1983.

This program was written by Stephen W. Wharton of **Goddard Space Flight Center.** *For further information, Circle 71 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center *[see page 29].* *Refer to GSC-12935.*

High-Level Data-Abstraction System

Communication with the database processor is flexible and efficient.

The High Level Data Abstraction (HILDA) system is a three-layer system supporting the data-abstraction features of the Intel data-base processor (DBP). The purpose of HILDA is the establishment of a flexible method of efficiently communicating with the DBP. The power of HILDA lies in its extensibility with regard to syntax and semantic changes. HILDA's high-level query language can be readily modified. HILDA offers powerful potential to computer sites where the DBP is attached to a DEC VAX-series computer.

Each layer within HILDA plays a specific role during communication with the DBP. The first layer is the Service Port Protocol (SPP), which provides an error-correcting asynchronous protocol to serve as the foundation for the other two layers.

The second layer of HILDA is the DBP Semantics Specification Package (DBPSSP), which enables the analyst easily to construct request blocks to be sent to the DBP. DBPSSP is a collection of assembly tools and serves as a cross-assembler. The DBP "machine code" is assembled on the host and then directed to the DBP for execution.

The third layer of HILDA is the DBP Query Language (DBPQL), which is a high-level query processor that enables the analyst to communicate with the DBP using English-like commands. DBPQL is designed to be used both by casual data-management users and by users with in-depth knowledge of DBP commands. DBPQL includes trace and performance commands to aid the analyst in implementing new commands and in analyzing the execution characteristics of the DBP. A parser generator package (PARGEN) is included to enable the analyst to create and manipulate easily the query statement syntax and semantics.

The HILDA system is written in Pascal and FORTRAN 77 for interactive execution. HILDA is designed for implementation on a DEC VAX-series computer with the VMS Level-3 operating system, an Intel DBP, and an RS-232 connection. The HILDA system was developed in 1983.

This program was written by Paul A. Fishwick of Kentron International, Inc., for **Langley Research Center.** *For further information, Circle 70 on the TSP Request Card.*
LAR-13244

Constant-Elasticity-of-Substitution Simulation

A computer program simulates production costs and uncertainties.

A program simulates the constant-elasticity-of-substitution (CES) production function. The CES function is used by economic analysts to examine production costs as well as uncertainties in production. The user provides such input parameters as the price of labor, price of capital, and dispersion levels. CES mini-

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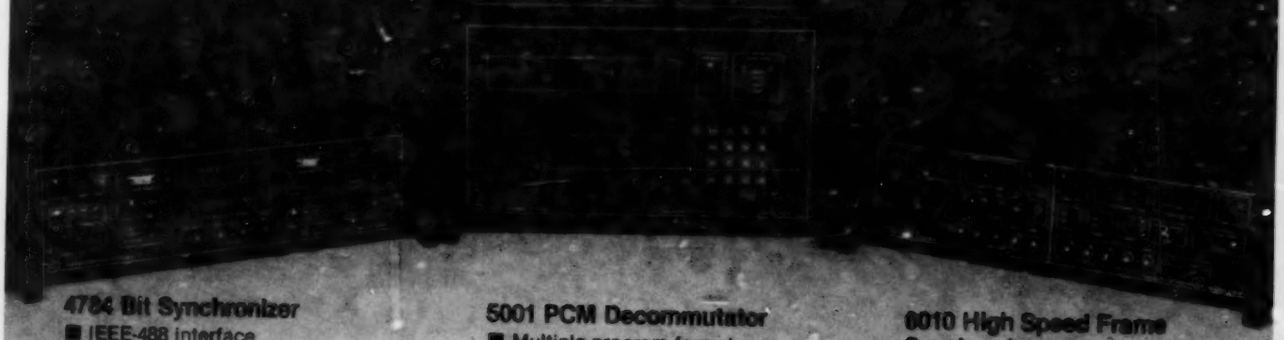

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mizes the expected cost to produce a capital-uncertainty pair. By varying the capital-value input, one obtains a series of capital-uncertainty pairs. The capital-uncertainty pairs can then be used to generate several cost curves. The CES program is menu driven and features a specific print menu for examining selected output curves.

Certain cost-curve data are stored in two formats: a floppy diskette file and a plot file. Some of the output-curve data are as follows: (a) capital versus uncertainty, (b) expected quantity of labor versus uncertainty, (c) expected total cost versus uncertainty, and (d) expected average cost versus quantity.

The CES program is written in BASIC for interactive execution and has been implemented on an IBM PC-series computer with a central-memory requirement of 64K of 8-bit bytes. The CES program was developed in 1984.

This program was written by Gregory Reiter of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 67 on the TSP Request Card.*
NPO-16524

An Expert-System Engine With Operative Probabilities

The program enables proof-of-concept tests of expert systems under development.

AESOP is a rule-based inference engine for an expert system, which makes decisions about a particular situation given user-supplied hypotheses, rules, and answers to questions drawn from the rules. If a knowledge base containing the hypotheses and rules governing an environment is available to AESOP, almost any situation within that environment can be resolved by answering the questions asked by AESOP. The questions can be answered with YES, NO, MAYBE, DON'T KNOW, DON'T CARE, or with a probability factor ranging from 0 to 10.

AESOP was developed as a tool for expert-system development. Although it is probably not suitable for the final implementation of most expert-systems applications, AESOP can serve as a fast means of developing a proof-of-concept test system. It also can be valuable in allowing the majority of the knowledge engineering to be done before commitment to a final implementation mechanism.

The sample AESOP rule file contains data for determining whether tasks in space should be automated or performed by humans. The initial prompt asks what task is under consideration, and AESOP asks questions about feasibility and performance until one of the original hypotheses (automate or perform by humans) is confirmed.

The rule file contains the initial prompt, the rules, and mutually exclusive rules used in the decisionmaking, the hypotheses, and the probability factors for each rule in a hypothesis. AESOP builds a top-down logic-tree structure. If a reply is DON'T KNOW, the rule base is checked for existing questions that may solve the dilemma. This allows several levels of rules to exist within a particular level containing more-specific decision criteria.

When any hypothesis reaches 90-percent certainty, AESOP prints a final confirming message. The user can ask WHY or HOW for a detailed list of the evidence confirming the hypothesis. The status of all initial hypotheses posed to AESOP is stored in a file for later reference.

AESOP is written in Franz LISP for interactive execution and has been implemented on a DEC VAX-series computer. The program was developed in 1984.

This program was written by Nancy E. Orlando and Michael T. Palmer of **Langley Research Center** *and Richard S. Wallace of Carnegie-Mellon University. For further information, Circle 68 on the TSP Request Card.*
LAR-13382

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Circle Reader Action No. 342

Mechanics

Hardware, Techniques, and Processes

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Variable-Friction Secondary Face Seals

Feedback-controlled friction or damping suppresses vibrations.

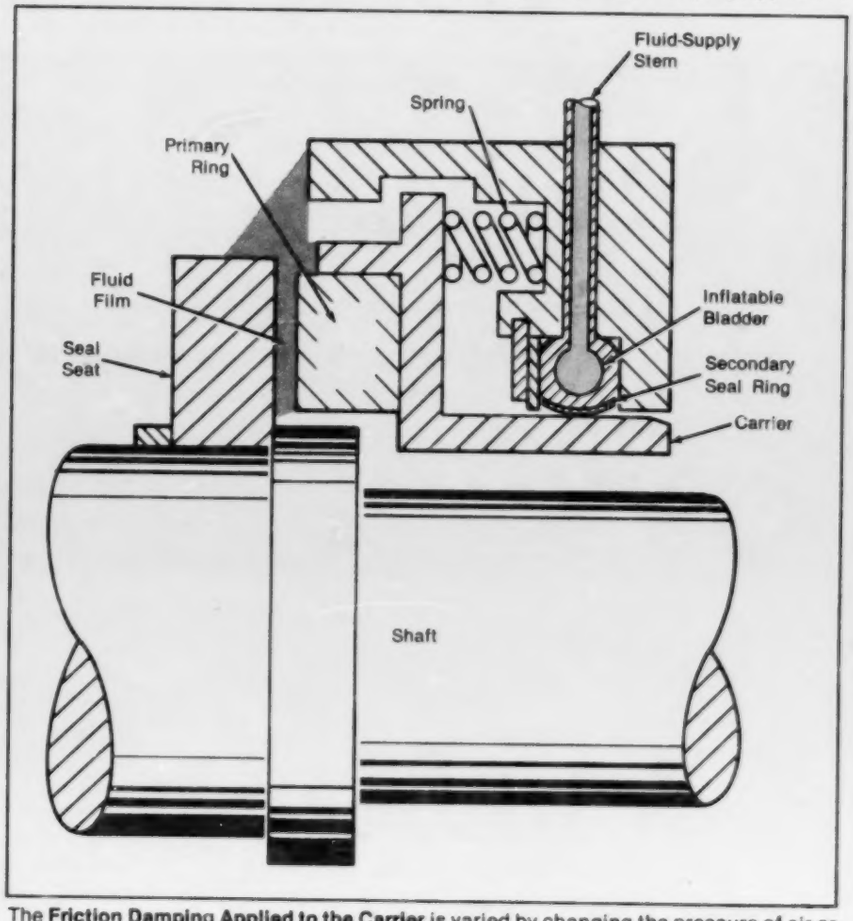
Lewis Research Center, Cleveland, Ohio

A variable-friction secondary seal has been conceived to control the vibration and stability of the primary seal ring over a wide range of conditions. By varying the friction force or damping applied to the primary seal ring, the vibration can be controlled to provide stable operation.

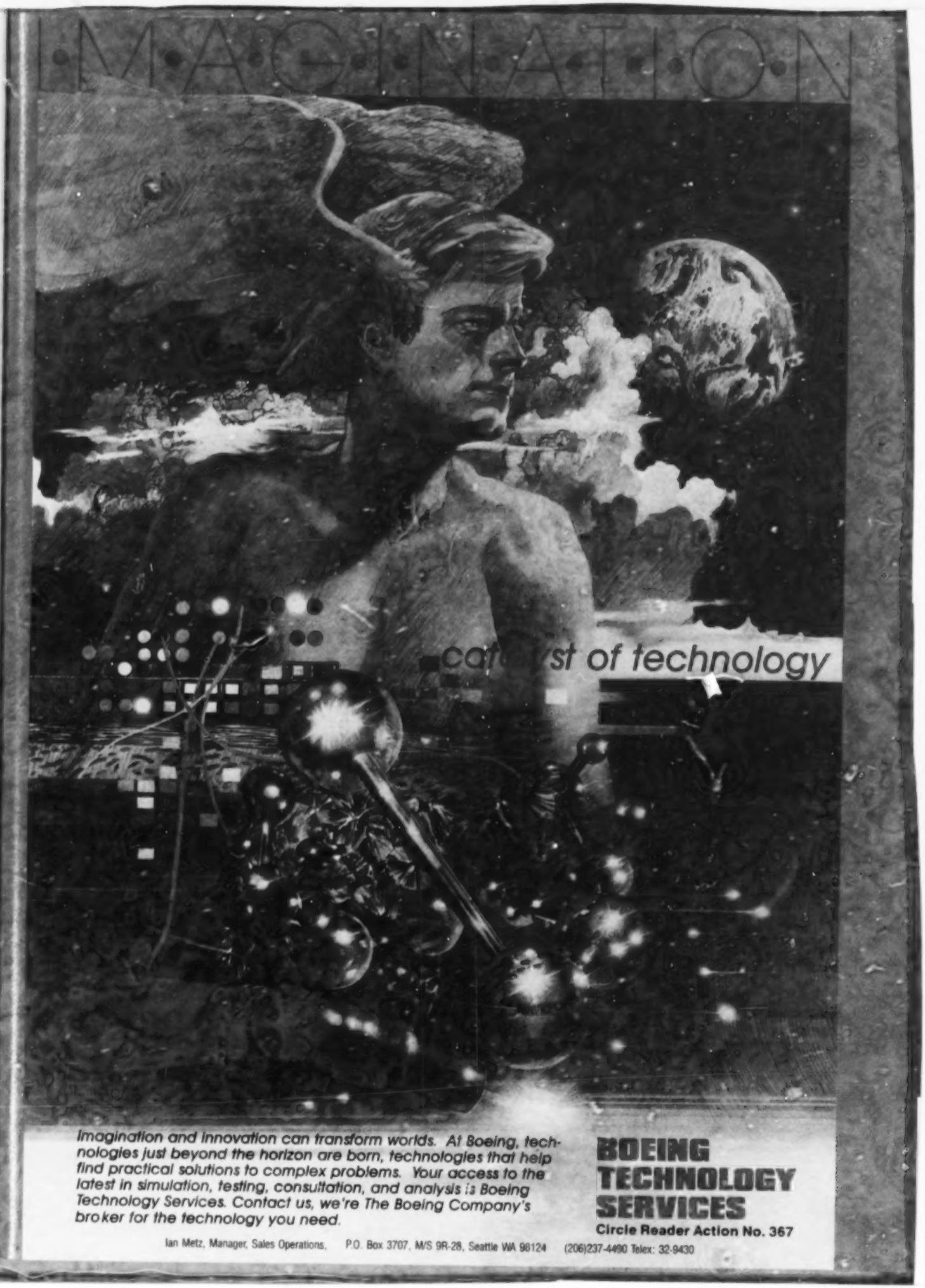
Self-acting face seals are a special type of face seal that operate with a very-thin liquid or gaseous film between the primary seal faces. In addition to the primary sealing face, face seals have a secondary seal, typically in the form of piston rings or elastomeric O-rings. The purpose of the secondary seal is to seal the secondary leak path in the face-seal assembly. Face seals are subject to instability due to the vibration of the primary seal ring. This results in excessive seal-face wear or failure.

Previous devices for producing the damping of primary-seal-ring vibration were of a static nature; i.e., the friction force was optimized for one seal-operating condition only. The disadvantage was that instabilities were encountered when seal conditions deviated from the design condition or when the seal was perturbed by transients.

As a means of alleviating this situation and allowing control over a wide range of conditions, the variable-friction secondary seal was conceived. The components of the "variable-friction secondary seal" (see figure) are the bladder and secondary seal ring, which has an axial split line. Operationally, variable friction and consequently variable damping are achieved by introducing air or hydraulic pressure through the stem into the bladder, which causes the bladder to expand into the secondary-seal ring. This changes the radial force and, consequently, the friction damping applied to



The Friction Damping Applied to the Carrier is varied by changing the pressure of air or fluid in the bladder.



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the carrier.

In the event that the seal film becomes unstable or the primary ring begins to vibrate, the bladder pressure is changed to mitigate the instability or vibration. The bladder pressure can be changed manually or by means of a feedback control system, which senses primary-ring vibration amplitude. The control system then changes the bladder pressure to minimize or limit the primary-ring vibration amplitudes within stable boundaries. The secondary-seal material may be selected to provide many different friction coefficients, and coatings may be applied to the secondary-seal ring to optimize the friction coefficient and sliding interface.

Advantages of the "variable-friction secondary seal" are that face-seal stability can be controlled as a function of primary-ring vibration amplitudes, and also the friction can be remotely changed to achieve acceptable vibration amplitudes for a large range of seal-operating conditions without compromising the secondary-seal performance. The concept is also useful in seal testing in which the dynamic stability of face seals is under evaluation.

This work was done by Eliseo DiRusso of **Lewis Research Center.** *No further documentation is available.*
LEW-14170

Measuring Thicknesses of Coatings on Metals

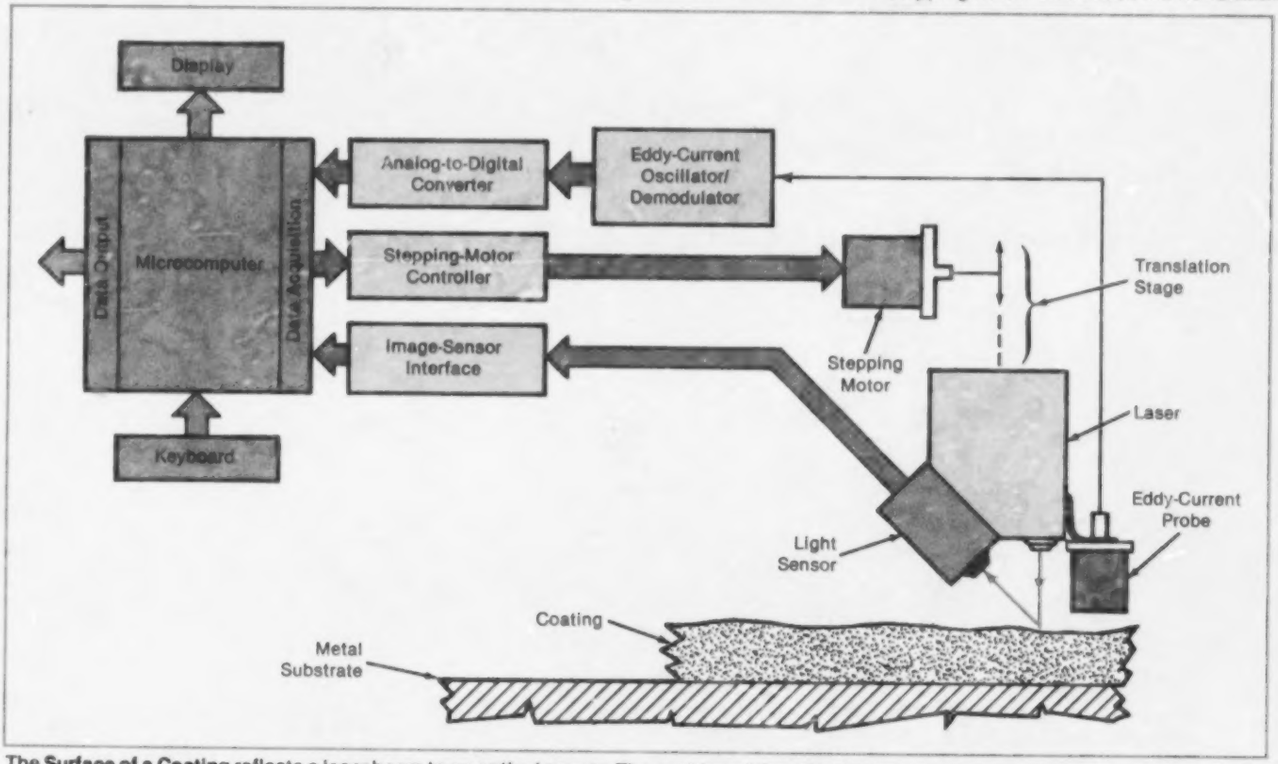
A digital light sensor and eddy-current sensor measure thickness without contact.

Marshall Space Flight Center, Alabama

Using laser-beam reflections and eddy-current sensing, an instrument measures the thicknesses of nonconductive coatings on metal substrates. When the capabilities of available components are fully exploited, the instrument will be able to measure coatings from 0.001 to 6 in. (0.0025 to 15 cm) thick with an accuracy of 1 part in 4,000. The instrument can readily be incorporated in automatic production and inspection systems. For example, it can be used to inspect thermal-insulation layers, paint, and protective coatings. It can also be used to control the application of coatings to preset thicknesses.

The eddy-current-sensing portion of the instrument maintains a reflected-light triangulation sensor at a fixed distance from the surface of the substrate as the substrate moves under it. The light sensor determines the angle and therefore the perpendicular distance of the laser-beam spot on the coating surface. With the laser kept at a fixed distance above the substrate by the eddy-current sensor, the angle to the laser spot is thus a function of the coating thickness. A microcomputer computes this thickness from the light-sensor angle measurement.

The eddy-current sensor and the light sensor are mounted together on a precise translation stage that moves toward or away from the coated substrate (see figure). The output of the eddy-current sensor is converted to a digital signal and is compared with the required sensor-to-substrate separation stored in the computer memory. The computer calculates the direction and magnitude of the separation error and sends a signal to the stepping motor that drives the translation



The Surface of a Coating reflects a laser beam to an optical sensor. The position of the reflected spot on the sensor is used by the microcomputer to calculate the coating thickness. The eddy-current sensor maintains a constant distance between the optical sensor and the metal substrate.

INTRODUCING A NEW SPACE SHUTTLE CAPABILITY

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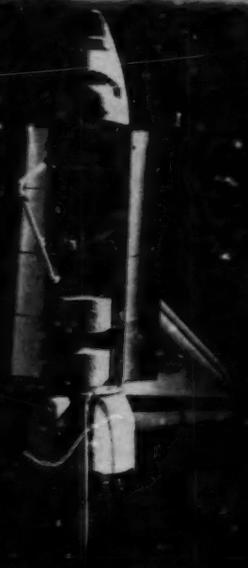

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stage. This adjusts the position of the sensors accordingly.

The light source is a helium/neon laser with a 1-mW output. The light sensor is an array of light-sensitive memory cells. When struck by photons, each cell discharges at a rate proportional to the product of light intensity and length of exposure. Before each measurement, the array is first refreshed with digital ones. Light is then focused on it to discharge the cells selectively. An image focused on the array is thus converted into a pattern of ones and zeros. The array is then read in the manner of an ordinary memory chip, and the angle information is extracted.

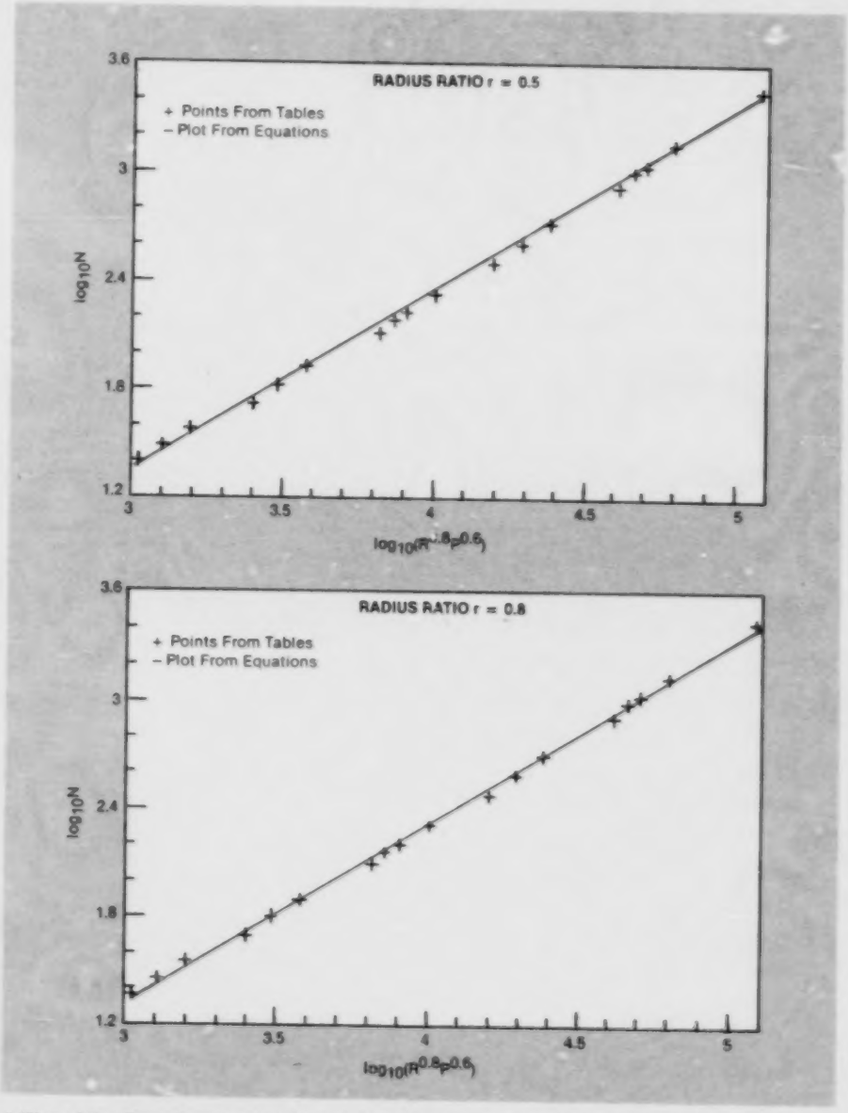
In addition to its other functions, the microcomputer can be used to control the movement of the sensors over the specimen surface. From a series of thickness measurements, it can also determine the waviness of the coating surface from the valleys and peaks of the thickness values and the distance between them.

This work was done by Glenn M. Cotty, Jr., of Martin Marietta Corp. for **Marshall Space Flight Center.** *For further information, Circle 89 on the TSP Request Card.*
MFS-28126

Equations for Annular-Heat-Transfer Coefficients

Tables of coefficients have been converted to algebraic expressions.

Marshall Space Flight Center, Alabama



A **Plot of the Equation for the Nusselt Number** agrees closely with points from tabulated data. The equation for the Nusselt number and those for coefficients A and B were obtained by a regression analysis of the data. Other plots (not shown) also show close agreement for radius ratios of 0.1 and 0.2.

A set of equations has been developed for heat-transfer coefficients for the annulus between the inner and outer tubes of a concentric-tube heat exchanger. Previously, the coefficients were available only in tabular form. In equation form, the coefficients can be incorporated into mathematical models more readily than as tabular data. The equations simplify the design and analysis of heat exchangers.

The equations were obtained by a regression analysis of the tabular data of W. M. Kays and E. Y. Leung, published in the *International Journal of Heat Mass Transfer* in 1963. The Nusselt number on the inner surface of an annulus with a constant rate of heat transfer and an insulated outer surface can be calculated as a function of the Prandtl number, the Reynolds number, and the annulus radius ratio, as follows:

$$\log_{10}N = A \log_{10}(R^{0.8}P^{0.6}) + B$$

$$A = -0.123r^2 + 0.172r + 0.937$$

$$B = 0.958r^2 - 1.336r - 1.217$$

where r = the ratio of the outside diameter of the inner tube to the inside diameter of the outer tube, R = the Reynolds number, and P = the Prandtl number.

These equations are correlated with the tabular data for $10^4 \leq R \leq 10^6$, $0.5 \leq P \leq 3$, and $0.1 \leq r \leq 0.8$. The coefficient of determination of the correlation is 0.987. The curves plotted from the equations agree well with the data points in the Kays and Leung tables (see figure).

This work was done by Barry Yao of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29074

Continuous, Multielement, Hot-Film Transition Gage

Measurements can be taken along a single line in the streamwise direction.

Langley Research Center, Hampton, Virginia

The accurate measurement of the location where a laminar boundary layer undergoes the transition to a turbulent one serves many purposes in basic aerodynamic research and developmental testing. For example, a complete understanding of performance, stability, and control of a laminar-flow airplane requires knowledge of transition locations on the wing surfaces, empennage surfaces, fuselage, and nacelles. Visual, acoustic, and electronic methods are capable of providing this transition information.

One very useful device for large-scale wind tunnel and flight applications is the thin, surface-mounted, hot-film gage. Hot films indicate transition by responding to the differences in heat transfer between laminar and turbulent flows. These gages are approximately as small as postage stamps and are applied to the test surfaces by conventional strain-gage installation techniques.

However, the wiring attached to the downstream end of each gage is large enough to cause a transition wedge (emanating downstream at about a 7° half angle); thus, these individual gages must be staggered to avoid the formation of false turbulence at the downstream gages (see Figure 1). This need for staggering is the source of the most significant disadvantages of individual hot-film gages.

The continuous, multielement, hot-film transition gage overcomes the disadvantages of the individual, hot-film gages by integrating the required number and distribution of hot-film sensing elements into a long, continuous, thin sheet. The length of the sheet covers the area of interest for transition measurements, beginning at the leading edge and continuing downstream of the transition region (Figure 2). For example, on an airplane wing of 10 ft (3 m) chord length, the gage might be as much as 7 or 8 ft (2.1 or 2.4 m) long.

The leading edge of a gage mounted on the upper surface of a wing would wrap around, beneath, and downstream of the wing leading edge. A method for installing the gage eliminates the formation of transition wedges at the lateral edges of the gage. The spanwise-facing step along the sides of the gage may be faired with thin adhesive tape, or, if necessary, filling materials can be used to fair these edges smooth. The gage adheres to the surface with a very thin [0.001-in. (0.0254-mm)] double-backed adhesive tape.

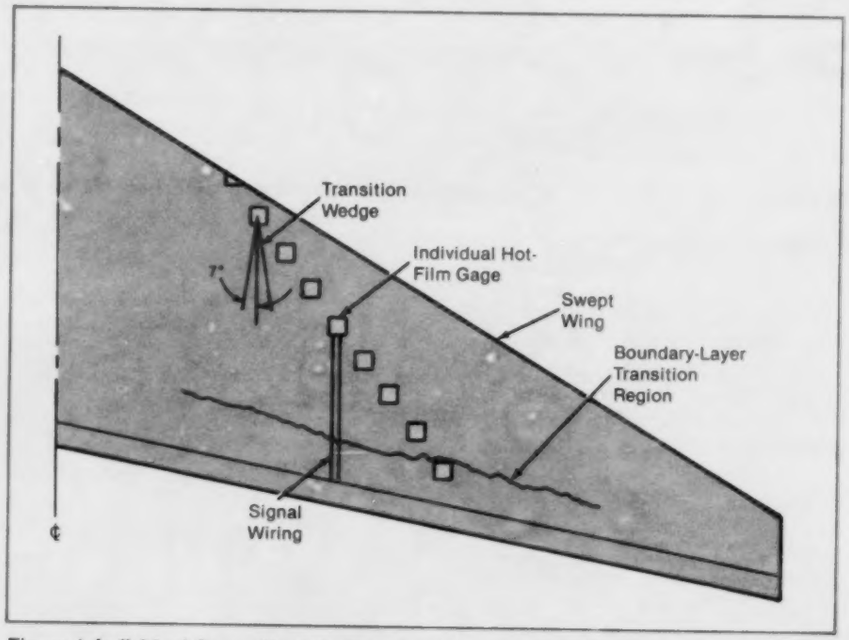


Figure 1. **Individual Gages Must Be Staggered** to prevent the formation of turbulence at the gages downstream. This arrangement precludes accurate measurements of laminar/turbulent transition regions along a streamline.

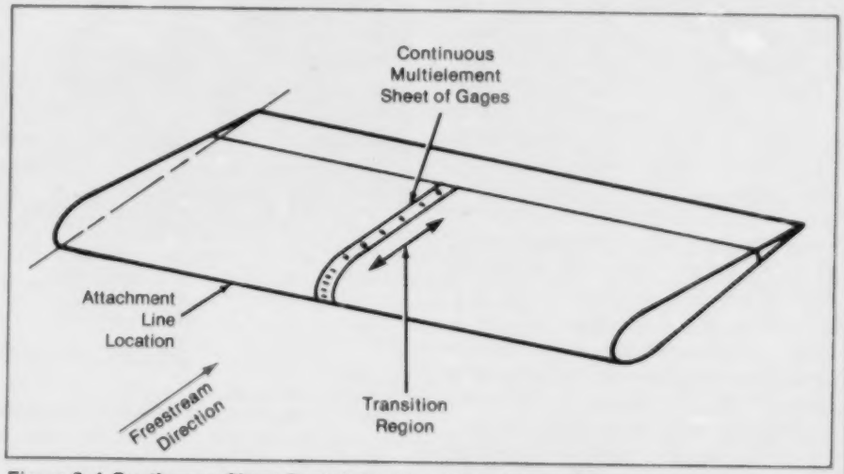


Figure 2. A **Continuous Sheet Containing Many Gage Elements** can be placed in line with the airstream without perturbing the flow and the flow measurements.

In this fashion, no disturbance from the film leading edge will cause turbulent wedges to affect the hot-film sensors in the transition region. The gage incorporates as many hot-film sensing elements as needed, distributed as needed along the length of the sheet. Because of the close spacing of the elements near the upstream end of the sheet, the stagnation-or attachment-line location can be documented. Further downstream, the elements are more widely spaced for transition-location measurement. The width of the sheet provides space for the signal leads to be carried laterally away from each

hot-film element and longitudinally to the downstream end of the sheet where external wiring arrangements are made.

The multielement gage uses an improved circuit that serves as an electronic switch. The switch is a power MOSFET (metal oxide/semiconductor field-effect transistor). It can switch far greater currents (10 A) than the hot-film elements require. The MOSFET switch does not oxidize as do conventional contacts, is not affected by vibration or acceleration, and is not position-sensitive. Its very high switching speed allows sensor elements to be switched into the servo loop at very high rates without damage to the sensors.

This work was done by B. J. Holmes, J. P. McPherson, F. K. Harris, J. K. Diamond, and N. R. Johnson of **Langley Research Center** *and J. J. Chapman of Kentron International, Inc. For further information, Circle 37 on the TSP Request Card. LAR-13319*

Two-Axis, Self-Nulling Skin-Friction Balance

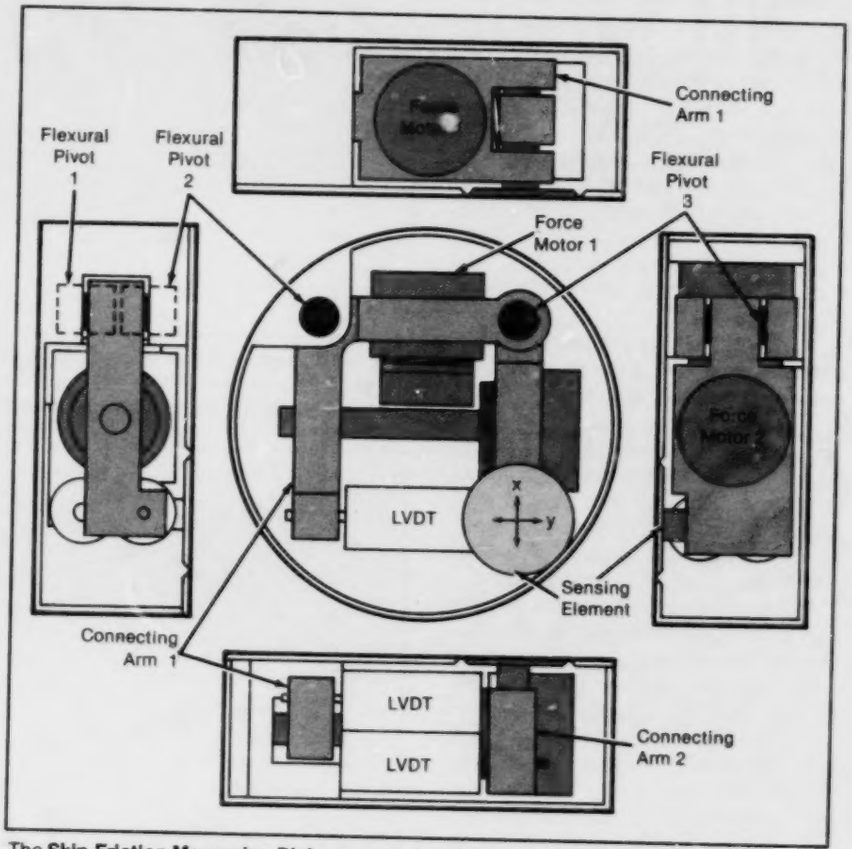
The two-dimensional aerodynamic skin-friction force is measured directly.

Langley Research Center, Hampton, Virginia

A two-axis, self-nulling skin-friction balance, designed to measure accurately the x and y components of the skin-friction force in the plane of airflow, is illustrated in the figure. The disk-shaped prototype design has overall dimensions of 1.25 inches (3.18 centimeters) diameter and 0.5 inch (1.27 centimeters) height. It is composed of two connecting arms, three flexural pivots, one sensing element, two force motors, two linear variable-differential transformers (LVDT's), and a case. A unique mechanism consisting of two flexural pivoted arms connected in tandem but at a right angle with each other is designed to impart the plane motion needed to sense the two-axis flow over the sensing elemen of the balance. The sensing element, 0.370 inch (0.940 centimeter) in diameter, that is attached to the end of the second arm is to be servoed by two restoring-force motors orthogonally mounted in the plane of airflow.

Two LVDT's will be used to provide the x-and y-axis displacement measurement for nulling the instrument. Care has been taken in the design of motor and LVDT housings to allow relative movements in these components only along their intended axes of operation. The balance is designed with a full-scale force range of 1 g (0.0098 N) in both x and y axes. The electronic circuit that provides the feedback signal for self-nulling operation and the continuous output signals is to be externally packaged.

A one-arm configuration with one restoring-force motor and a single LVDT can be used for the design of a miniature single-axis skin-friction balance. Also, the two-axis configuration can be converted into a three-dimensional or three-axis device by attaching a third pivoted arm in series but normal to the plane formed by the other two arms. The two- or three-axis configurations can also be designed to measure the velocity vectors of waterflow.



The **Skin-Friction Measuring Disk** connected to the sensing element measures the x and y components of skin friction in the plane of airflow.

The present design measures directly the skin-friction force over a single sensing element. The two-axis mechanism allows the free plane motion of the sensing element with no friction, and the balance is self-nulled to provide direct plane skin-friction force measurements continuously.

This work was done by Ping Tcheng and Frank H. Supplee, Jr., of **Langley Research Center.** *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13294.

Acoustic-Liner Admittance in a Duct

The method calculates the admittance from easily obtainable values.

Langley Research Center, Hampton, Virginia

The acoustic admittance of practical acoustic liners may be a function of the aeroacoustic environment in which they are located. The properties of these liners in such an environment are evaluated in the laboratory with a grazing-flow impedance tube. In such a tube, the acoustic material is alined so that the sound and mean flow graze over the surface of the material in a controlled manner to simulate the environment typical of that found in a real jet engine.

Since acoustic admittance is defined as the ratio of normal particle velocity to pressure at the wall surface, the admittance could be determined experimentally by direct measurements of normal particle velocity and pressure.

In practice, measurements of particle velocity in the presence of grazing flow are currently not reliable. Instead, an indirect approach must be taken, which depends only on the measurement of acoustic pressure at selected locations in the test configuration. These measurements are then used as input to an analytical program that determines the admittance based on these measured data.

Previous methods for determining acoustic admittance in grazing flow, from measured values of the axial propagation constant and cross modes, are based on the solution to an ordinary differential equation and are restricted to mean flows with transverse gradients in one direction only. However, grazing-flow duct facilities commonly employ ducts with relatively small rectangular cross sections in which the grazing flow possesses gradients in both transverse directions of the impedance tubes. Such is the case in the flow-impedance test laboratory at Langley Research Center; therefore, the present effort was motivated by the need to account for the more realistic flow environment in laboratory flow-impedance tubes such as those in the Langley facility.

The new method for calculating acoustic-liner admittance in a rectangular duct with grazing flow is based on a finite-element discretization of the acoustic field and a reposing of the unknown admittance value as a linear eigenvalue problem on the admittance value. This eigenvalue problem is solved by Gaussian elimination. Unlike existing methods that are based on the integration of an ordinary differential equation and are thus limited to mean flows with one-dimensional boundary layers, the present method is extendable to mean flows with two-dimensional boundary layers as well.

Admittance values determined from the method compared excellently with the exact solutions obtained for a constant mean flow profile. In the presence of shear, the results of the method compared well with the results of a Runge-Kutta integration technique.

This work was done by Willie R. Watson of **Langley Research Center.** *Further information may be found in NASA TP-2310 [N84-27543/NSP], "A New Method for Determining Acoustic-Liner Admittance in a Rectangular Duct With Grazing Flow From Experimental Data" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

LAR-13399

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Circle Reader Action No. 421

Sensing Horizontal Heading in Aircraft Maneuvers

A modified gyroscopic system indicates the geographic heading even in nearly vertical flight.

Dryden Flight Research Center, Edwards, California

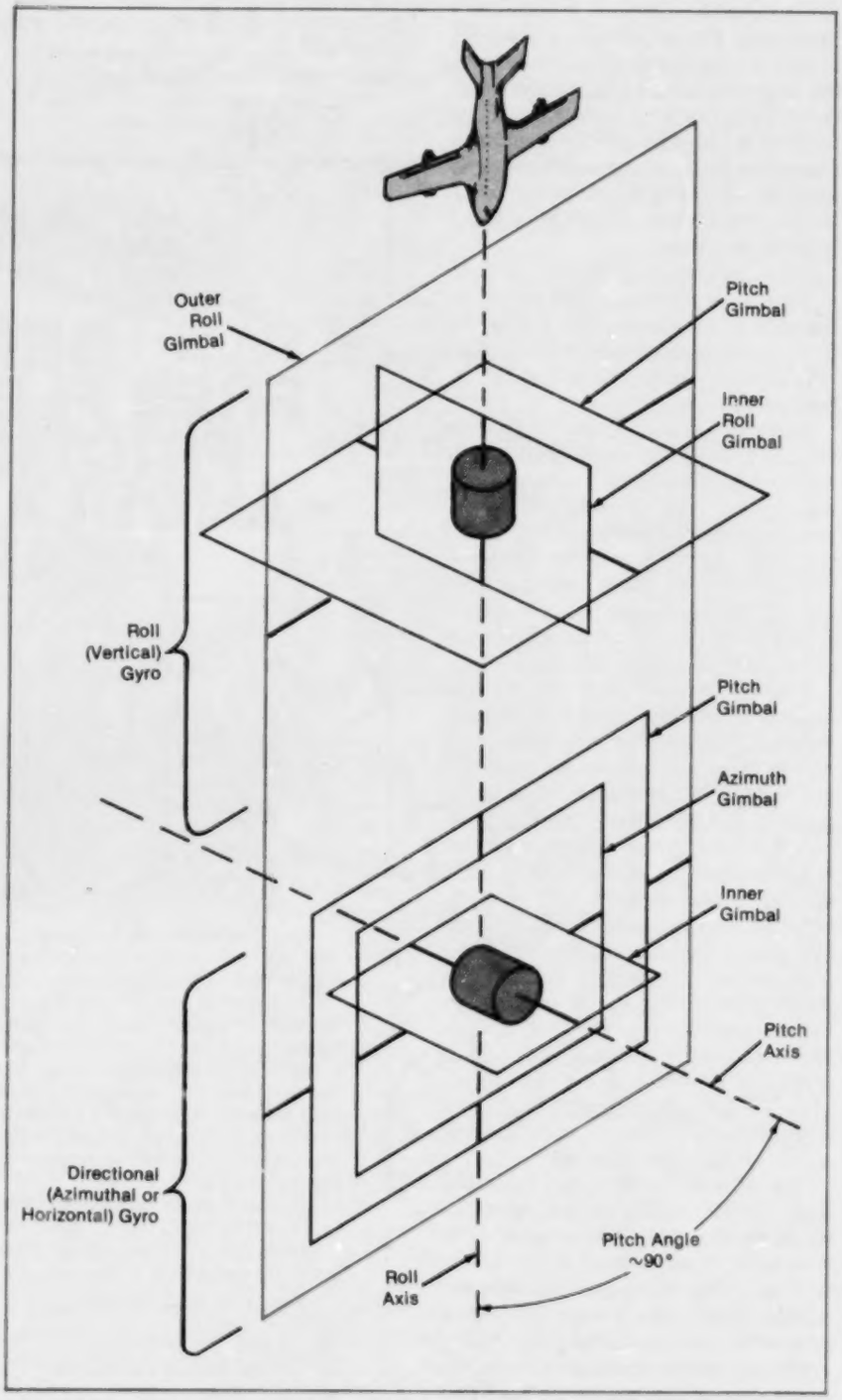
Modifications to an existing two-gyroscope attitude-sensing system supply azimuth (geographic heading) information, rather than the usual roll information when the aircraft climbs or dives within 15° of vertical. Previously, no azimuth heading was available during nearly vertical flight due to the nature of the gimbal-lock-avoidance subsystem. Now, the azimuth signal in the modified system indicates what the aircraft heading would be if it were to resume level flight from a climb or dive.

The relationship among the gimbals, gyroscopes, and aircraft axes during a nearly vertical dive is shown in the figure. In the unmodified system, the outer roll gimbal is held fixed in space when the pitch axis comes within ±15° of vertical. This causes the azimuthal gimbal to become fixed with respect to the outer roll gimbal, even when the small horizontal component of the aircraft heading changes: Thus, the horizontal (directional) gyro ceases to supply a correct azimuth-heading signal.

In the modified system, the outer roll gimbal is held fixed with respect to the aircraft frame when the pitch angle is within ±15° of vertical. A roll about the longitudinal axis then causes a movement of the pitch gimbal about the azimuthal gimbal, which gives rise to an azimuthal indication as in level flight. If the roll were to suddenly stop and the aircraft pitched back to level, the resulting aircraft azimuthal heading would be indicated correctly.

The outer roll gimbal, the pitch gimbal, and the inner gimbal of the vertical (pitch) gyro remain mutually orthogonal during nearly vertical maneuvers. Therefore, when the aircraft pitches from vertical toward horizontal flight, the outer roll gimbal is free to follow the aircraft platform without disturbing the spatial orientation of the pitch and inner roll gimbals of the vertical gyro. Similarly, departure from vertical flight induces no movement of the inner gimbals of the horizontal (directional) gyro. Thus, the probability of gyro tumble due to gimbal lock during such maneuvers is reduced.

Antitumble performance is improved over that of the original system except when the aircraft enters nearly vertical



The **Gyroscopes and Gimbals** of the system assume this configuration when an aircraft has pitched into a vertical dive. The outer roll gimbal is fixed with respect to the aircraft frame in this orientation.

flight while at or near a 90° roll angle. In that case, antitumble capability matches that of the original system.

This work was done by Kenneth T. Cowdin of **Dryden Flight Research Center.** *For further information, Circle 41 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,387,513). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to FRC-11043.

Measuring Acoustic-Radiation Stresses in Materials

This system measures the nonlinearity parameters of materials.

Langley Research Center, Hampton, Virginia

The acoustic-radiation-stress measurement system was developed to provide a means to characterize quantitatively those properties of fluids and solids related to material nonlinearity. Each material has a unique set of nonlinearity parameters that characterizes the material and that is related to its thermodynamic state. The thermodynamic state is generalized here to include the degree of residual or applied stress, the atomic or molecular composition of the material, defect structures, and the state of material order or disorder. The nonlinearity parameter thus serves as an important and distinct measure of the material state and is both complementary and supplementary to acoustic-velocity and acoustic-attenuation measurements.

The nonlinearity parameter accounts for acoustic-waveform distortion leading to the generation of harmonics of the fundamental driving acoustic frequency and to acoustic-radiation-induced static strains in the material. These strains are a manifestation of the acoustic-radiation stress in the material.

The measuring system uses the static strain generated by an acoustic wave propagating in the material. Since the static strain is effectively a "dc" component of the waveform distortion, problems associated with phase-cancellation artifacts disappear. Further, the sign of the nonlinearity parameter is obtained by simple inspection of the measured signal polarity. These features make this system very amenable to use in the field.

The theory of acoustic-radiation stress and the resulting radiation-induced static strain, only recently understood, serves as the basis for this system. The nondestructive-evaluation laboratory at Langley Research Center is using the system to characterize material nonlinearity in solids and liquids and has uncovered material properties not previously known. The system is expected to become a standard for acoustic-radiation-stress measurements for solids and liquids and for the characterization of material properties related to strength and residual or applied stresses. It is also expected to become a standard for transducer calibration.

This work was done by John H. Cantrell, Jr., and William T. Yost of **Langley Research Center.** *For further information, Circle 100 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13440.

Spring-Loaded Joule-Thomson Valve

The improved design reduces clogging and maintains a constant pressure drop as the flow rate varies.

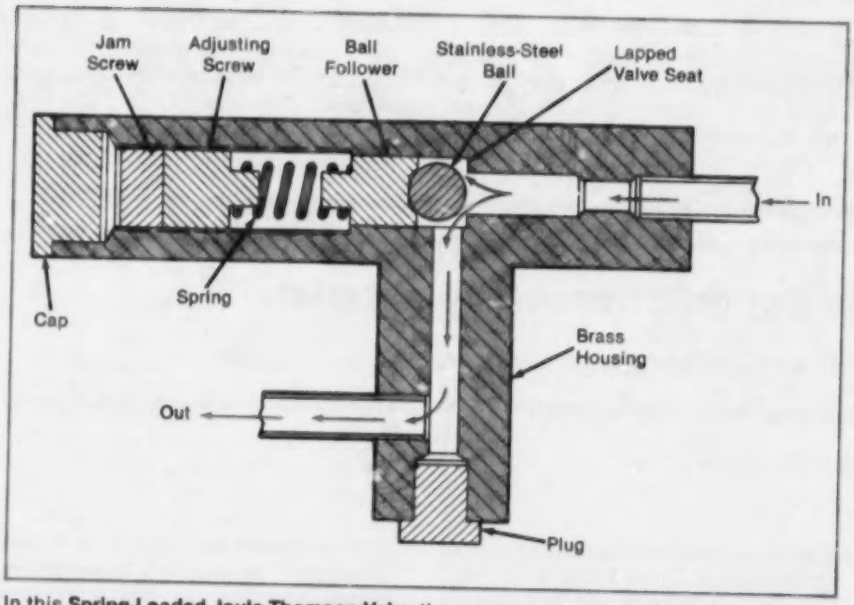
NASA's Jet Propulsion Laboratory, Pasadena, California

A spring-loaded Joule-Thomson (J-T) valve permits optimal cooling-power regulation of a J-T refrigerator by allowing independent adjustment of the flow rate and pressure drop through the valve. Because the spring-loaded J-T valve maintains a constant pressure drop, an upstream room-temperature throttle valve can adjust the flow rate precisely for any given upstream pressure. In addition, the new valve is relatively invulnerable to frozen gas contaminants, which can clog fixed-orifice J-T valves.

Conventional J-T expansion valves have fixed orifice openings; the pressure drop through these openings depends on the helium flow rate. Moreover, any trace amount of frozen gas contaminants could block such openings, drastically changing the cooling power of the refrigerator.

The new valve operates very much like a variably-loaded check valve. The orifice is regulated by a steel ball pushed by adjustable spring tension against a soft brass seat (see figure). The steel ball is raised off the seat whenever the force of the upstream pressure exceeds the spring force. Thereafter, a nearly-constant pressure drop is maintained as long as the gas flows by the spring-loaded ball. An increase in the flow rate merely lifts the ball further, the pressure drop being almost unaffected. Contaminants that freeze out on the ball or seat lift the ball slightly further, but do not clog the valve permanently, as in a fixed-orifice J-T valve.

The metal-to-metal seat is more attractive for cryogenic applications than plastic



In this **Spring-Loaded Joule-Thomson Valve** the pressure drop is regulated by the spring pushing the stainless-steel ball against a soft brass seat. The pressure drop remains nearly constant, regardless of the helium flow rate and of any gas contaminants frozen on the valve seat.

seating materials, which tend to deform more than metals at low temperatures. Also the ball-and-socket approach is better than valve-poppet/O-ring designs, because a ball-and-socket design is self-centering. The new design also allows for external adjustment of the flow rate by means of a room-temperature throttle valve upstream of the J-T valve. Because the spring stiffness varies with temperature, the pressure drop at liquid-helium temperatures (typically 4.5 K) is about 4 percent higher than at room temperature.

The valve was tested on a cryogenic refrigerator used for maser receivers. At the throttle valve, the pressure dropped from 282 psia (1.94×10^6 N/m^2) to 262 psia (1.81×10^6 N/m^2); and at the spring-loaded J-T valve, from 262 psia (1.81×10^6 N/m^2) to 20 psia (1.38×10^5 N/m^2) while the temperature at the J-T valve was maintained at 4.5 K.

This work was done by Jack A. Jones and Michael J. Britcliffe of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 8 on the TSP Request Card.*
NPO-16546

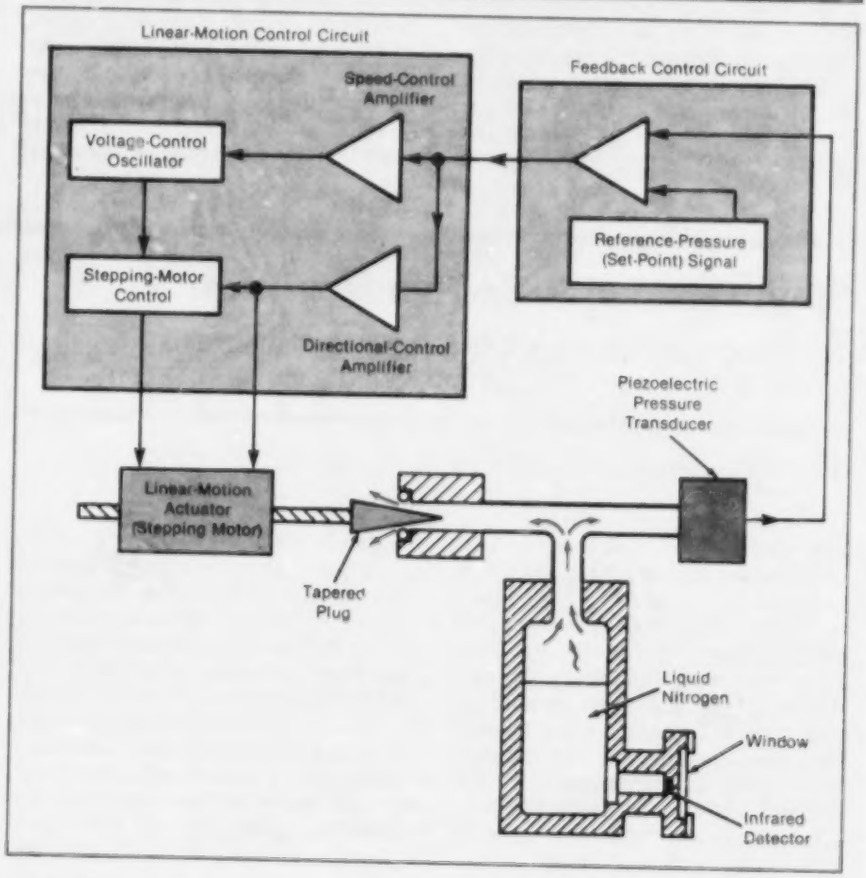
Feedback-Controlled Regulation of Gas Pressure

Internal pressure is maintained over a wide range of external pressures and exhaust rates.

Goddard Space Flight Center, Greenbelt, Maryland

A feedback-controlled variable orifice regulates gaseous-nitrogen pressure in a liquid-nitrogen Dewar flask with precision of ±0.001 psi (7 N/m^2) over an ambient-pressure range of 26 to 756 torr (3.5 to 100 kN/m^2) and over a wide range of anticipated flow rates. Designed specifically to maintain airborne infrared detectors at a constant temperature in evaporating liquid nitrogen, this system can be modified to regulate the pressure in other enclosed systems.

Previous liquid-nitrogen pressure regulators have been of the passive mechanical type. Typically, these have a regulating accuracy no greater than ±1 psi (7 kN/m^2) at a given flow rate. Moreover, with these pressure regulators, the regulated pressure varies as the exhaust rate changes with the am-



The **Gaseous Pressure in a Liquid-Nitrogen Dewar** is regulated by a movable tapered plug, positioned automatically in response to signals generated by a piezoelectric pressure transducer.

bient pressure. The internal pressure also varies as system motion affects the evaporation rate of the liquid nitrogen.

The feedback-controlled, variable-orifice system is shown schematically in the figure. The exhaust opening of the liquid-nitrogen Dewar is connected to a variable-orifice mechanism that provides a variable-area port for the exhausting gaseous nitrogen. Also connected to the exhaust opening is a piezoelectric pressure transducer. The transducer sends the electronic control circuit a signal proportional to the gaseous-nitrogen pressure.

The control circuit compares the pressure-transducer signal to the set-point signal and puts out an error signal proportional to the difference between them. The error signal is sent to the linear-motion control circuit, which causes a stepping motor to move a cone-shaped plug within the exhaust orifice. The position of this plug determines the effective exhaust opening, thereby causing the Dewar pressure to be returned to the setpoint.

The use of a low-friction valve mechanism reduces the requirement for precise machining during the manufacture of the valve parts: There is no need for the highly polished surfaces that would be necessary if the valve were designed differently. The electronic control circuit controls the valve with the same precision over its entire range of operation. The valve-operating range can be changed easily, with minimal mechanical alterations, to allow for any reasonable anticipated flow rate.

This work was done by James C. Smith and Peter Leone of **Goddard Space Flight Center.** *For further information, Circle 6 on the TSP Request Card.*
GSC-12990

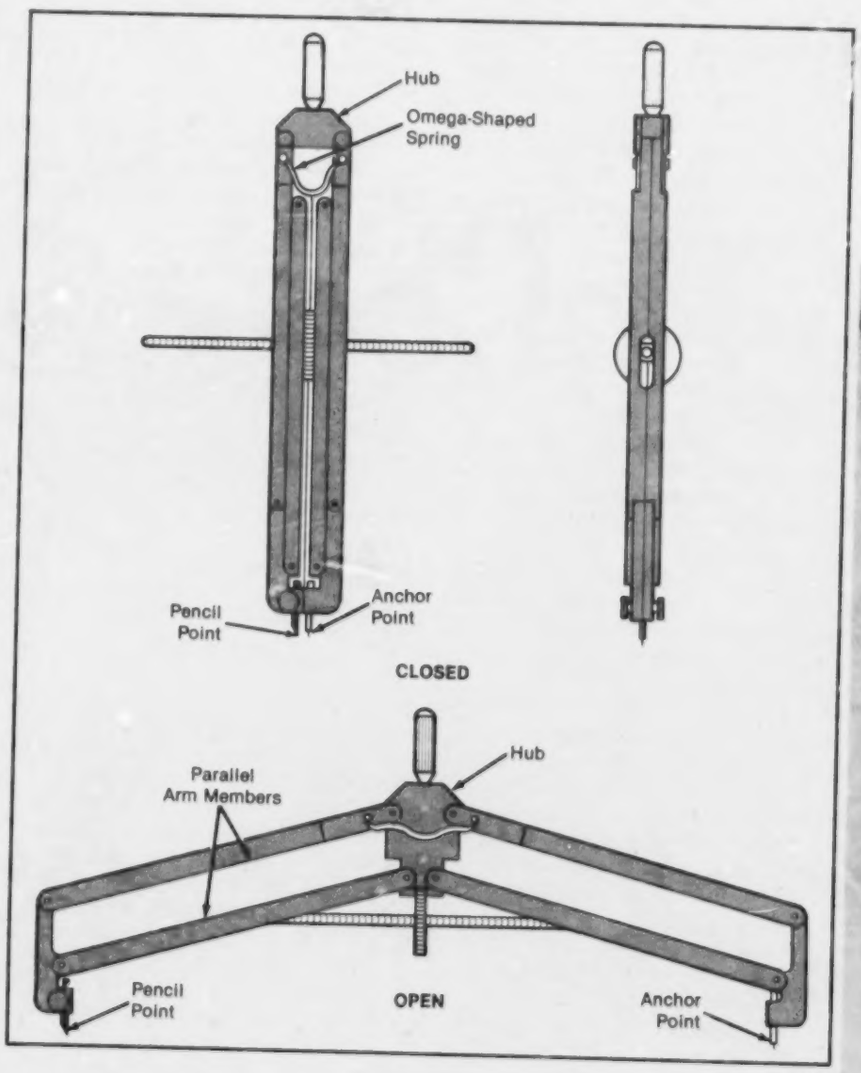
Parallel-End-Point Drafting Compass

A parallelogram linkage ensures greater accuracy in drafting and scribing.

Marshall Space Flight Center, Alabama

A linkage on a drafting compass keeps the pointed compass ends always in parallel, regardless how widely one opens up the compass legs. When the pointed ends are in parallel, distance measurements become more precise than with inexpensive compasses or dividers that have their pointed ends extending radially from the hub. Errors on these inexpensive instruments occur because the points sink into the paper at an angle, and the more one opens up the compass legs, the larger the angle and the greater the error. More expensive compasses and dividers have adjustable points, but these have to be set individually for each new radius to keep the pointed ends in parallel. The new compass employs a parallelogram linkage between its ends and its hub. The ends are in parallel when the compass is closed, when it is fully open, and at all positions in between. A pair of omega-shaped springs secures the linkage arms in the position set by the user until the user readjusts the end spacing. The parallelogram-linkage principle can be used on dividers as well as on compasses.

This work was done by J. A. Cronander of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29070



The **Two Members of an Arm** of the compass remain parallel for all angles the pair makes with the hub axis. They maintain the opposing end members in parallelism.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Evaluation of Mathematical Turbulence Models

Simplified models for internal flow are described, and their predictions are compared with experimental results.

A report presents an account of various models used in the computation of turbulent flows. The applications of these models to internal flows are evaluated by the analysis of the predictions of various turbulence models in some important flow configurations.

Internal flows are complicated and are involved in many practical applications: These include flows in pipes, ducts, conduits, diffusers, and heat exchangers. Turbulence makes the flow equations even more complicated, necessitating the use of simplified mathematical models to obtain approximate solutions.

The report describes models of incompressible flows in which the velocities, stresses, and other dependent variables are separated into steady (that is, time-averaged) and fluctuating components. Some of the models also involve spatial averaging over such small regions as boundary layers. Attention is focused on the k-ε model (where k = the time-averaged local density of the kinetic energy of the turbulence and ε = the dissipation rate of the energy of the turbulence). The k-ε model relates the eddy viscosity to k and ε.

The main conclusions of the report are as follows:

- The k-ε model is the most widely used model for engineering calculations of internal flows. The performance of the standard k-ε model becomes poorer as one goes from attached flow to recirculating, swirling, and combusting flows, in that order.
- The standard k-ε model performs poorly in the prediction of apparently simple flow over a backwardly facing step. There is no significant improvement in the value of reattachment length predicted with modified near-wall models. The algebraic stress model (a sort of extended k-ε model) should be used, with a modified k-ε equation.
- The k-ε model performance is rather poor for flows with streamline curvature. The algebraic stress model performs better for these flows.
- Reynolds stress models (involving approximations of diffusion, viscous dissipation, and other quantities) have not been thoroughly tested for recirculating flows and swirling flows. The computational effort required for a Reynolds stress model is much greater than that required for the k-ε model.
- For flows with regions of secondary flow (flows in noncircular ducts), the algebraic stress model performs fairly well for fully developed flow, but not for a developing flow. A Reynolds stress model should be used for the developing flow.
- Many computations should be viewed with caution because the dependence of the solutions on the coarseness of the computational grid has not been tested.
- The initial conditions play a crucial role in the performance of a model and the predicted solutions.
- The TEACH (Teaching Elliptic Axisymmetric Characteristics Heuristically) code, or its variant, is the most widely-used computer code in the prediction of turbulent internal flows cited in the literature.

Two important factors in the numerical solution of the model equations are discussed; namely, false diffusion and inlet boundary conditions. The existence of countergradient transport and its implications in turbulence modeling are mentioned. There are brief descriptions of other approaches to turbulent-flow computations including the vortex method (using point or line vortexes), large-eddy simulation (direct solution of the Navier-Stokes equations with filtering to remove small eddies), and direct simulation (solution of the full Navier-Stokes equations).

This work was done by M. Nallasamy of **Marshall Space Flight Center.** *Further information may be found in NASA Technical Paper 2474 [N85-25757/NSP], "A Critical Evaluation of Various Turbulence Models as Applied to Internal Fluid Flows" [$11.95]. A paper copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 90 on the TSP Request Card.*
MFS-27118

Correcting for Supports in Structural Dynamic Testing

Testing under a variety of support conditions is combined with computer analysis to update mathematical models to match test data.

A report suggests that the dynamic characteristics of large space structures can be predicted, without full-scale testing, by a method that combines experiment and analysis. The method, multiple-boundary-condition testing, was developed for such large space structures as dish antennas, towers, and solar-cell arrays.

The method compensates for the effects of the supports that are needed to hold flexible and fragile space structures when they are tested in Earth's gravity. Multiple-boundary-condition testing consists of testing a structure under a variety of support conditions and support locations. The resulting data are processed according to an algorithm that separates the meaningful information about the structure from the spurious effects of the supports.

The initial input data for the mathematical model of the structure are represented by mass and stiffness matrices. The equations that give the theoretical data relating to the vibrational modes are linearized, then fitted to the test data by a least-squares method. The revised estimates are then used to calculate the data relating to the vibrational modes. This process is repeated until the correlation between the mathematical and the test results is acceptable.

The report reviews the history of the development of the method, presents the principles of the approach, discusses the results of a theoretical analysis of the accuracy of the method in comparison with conventional testing, and describes a computer simulation of the method as applied to a simply supported beam with a series of roller constraints. Initial studies indicate that the method can provide a better final mathematical model of a structure than can a conventional ground test of the structure.

This work was done by Ben K. Wada, Chin-Po Kuo, and Robert J. Glaser of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Multiple Boundary Condition Testing Used To Validate a Structural Dynamic Model of a Large Flexible Structure," Circle 39 on the TSP Request Card.*
NPO-16620

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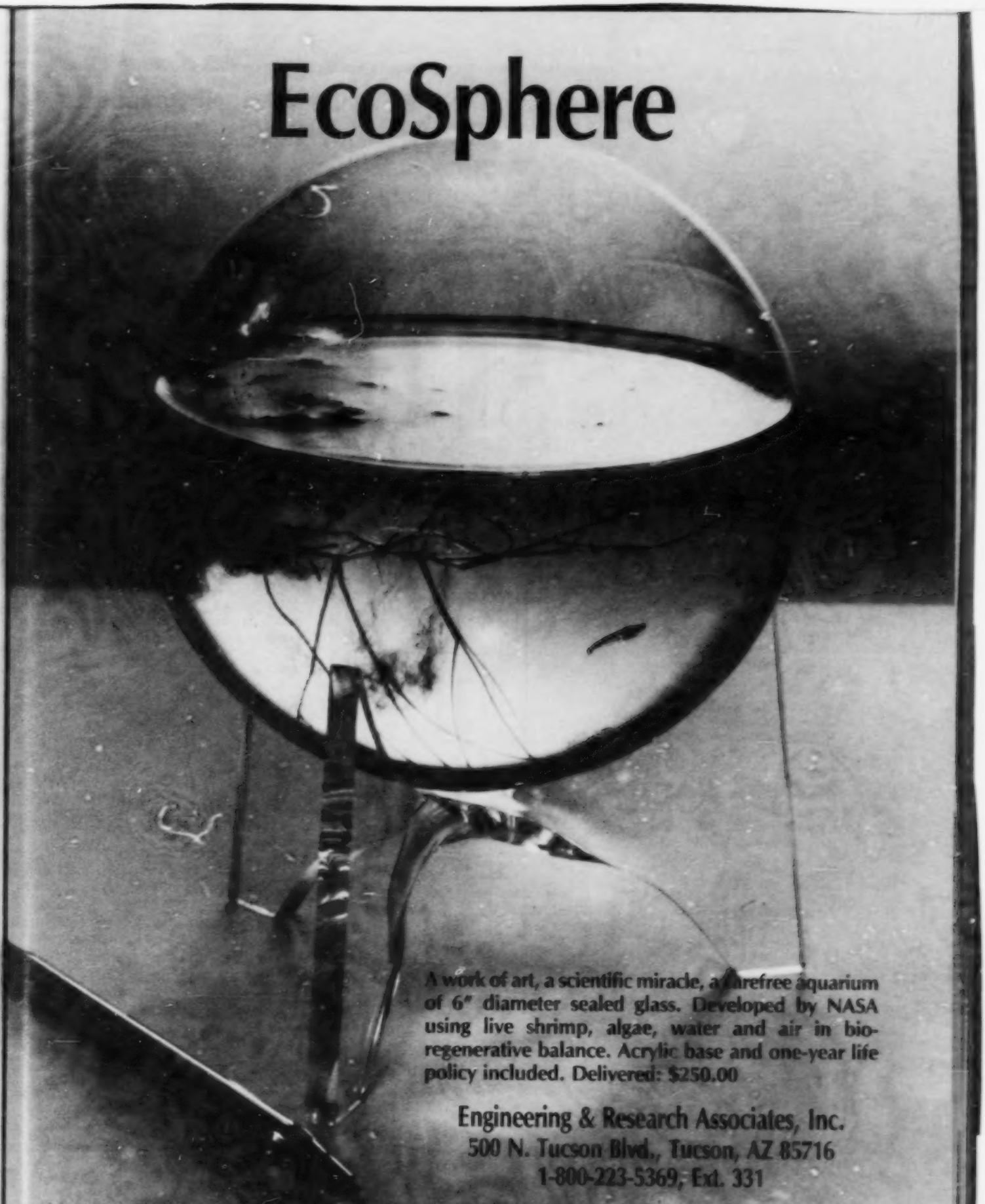

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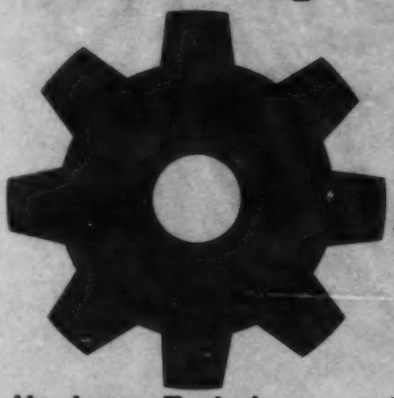

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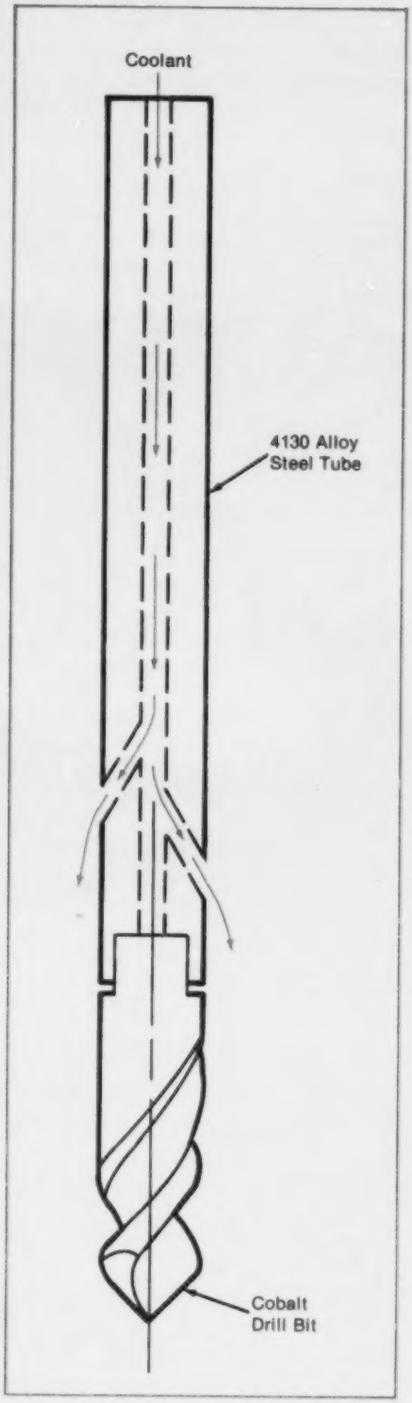
Modified Cobalt Drills With Oil Passages

Oil is forced through the drill shanks to lubricate the cutting edges.

Marshall Space Flight Center, Alabama



Drill bits have been cooled and lubricated by oil forced through the drill shanks and out holes adjacent to the bits. This cooling technique increases drill-bit life and allows increased drill feed rates.

The particular application involved the removal of inertia-weld nuggets from the bottoms of holes 10 in. (25.4 cm) long with 0.188 in. (0.47 cm) diameter. The nugget material is left after inertia welding of Haynes 188 (or equivalent) posts (containing the holes) to Inco 718 (or equivalent) stubs. The nuggets are irregularly shaped with inconsistent material properties.

Carbide drill bits tend to break from the surface irregularities, making cobalt a better cutting tool material. However, cobalt drill bits dull rapidly without adequate cooling. The drill diameter is only 0.010 in. (0.025 cm) less than that of the hole. The conventional cooling method fails to get coolant to the cutting surface of the drill at the bottom of the hole.

The solution to the problem is shown in the figure. The drill shank is joined with a tube having three exit holes 120° apart near the shank end. Cooling oil is forced through the tube and out the exit holes toward the bit.

This work was done by E. E. Hutchison and D. Richardson of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29137

During Drilling the Bit Is Cooled by oil forced through the shaft and out holes near the bit.

Spiral-Groove Ring Seal for Counterrotating Shafts

The self-lubricating seal tolerates high sliding speeds.

Lewis Research Center, Cleveland, Ohio

The spiral-groove intershaft ring seal is a new seal concept that has potential application in sealing fan-bleed air between two counterrotating shafts in advanced gas-turbine engines. This is a difficult sealing application for any contacting-type seal because the counterrotating shafts set up very high sliding speeds for the seal. In addition to the high sliding speed, the seal must accommodate axial translation due to relative axial motion between the two shafts.

The intershaft ring-seal application is an excellent example of the need for applying self-acting, gas-lubricating bearing technology to contacting-type seals. Application of a self-acting geometry in the form of spiral grooves to the faces of the ring-seal housing will maintain a thin air film of relatively high stiffness between the seal ring and the housing, thereby enabling the seal to operate in a noncontacting mode over the entire engine-operating range. The seal could then operate at high sliding speeds, accommodate axial translations, and have leakage rates consistent with contacting-type seals.

When spiral grooves are employed in a seal as a film-generating mechanism, the following are generally required to calculate the axial-force equilibrium: (1) film load-capacity curves (lift force as a function of film thickness), (2) minimum film thickness over the operating range, and (3) optimization of the spiral-groove geometry to maximize the lift force for a given seal-envelope size and operating condition. Figure 1 shows the intershaft seal concept. The housing, which contains the carbon ring, rotates with the inner shaft. The carbon ring is bounded on its outside diameter by the outer shaft,

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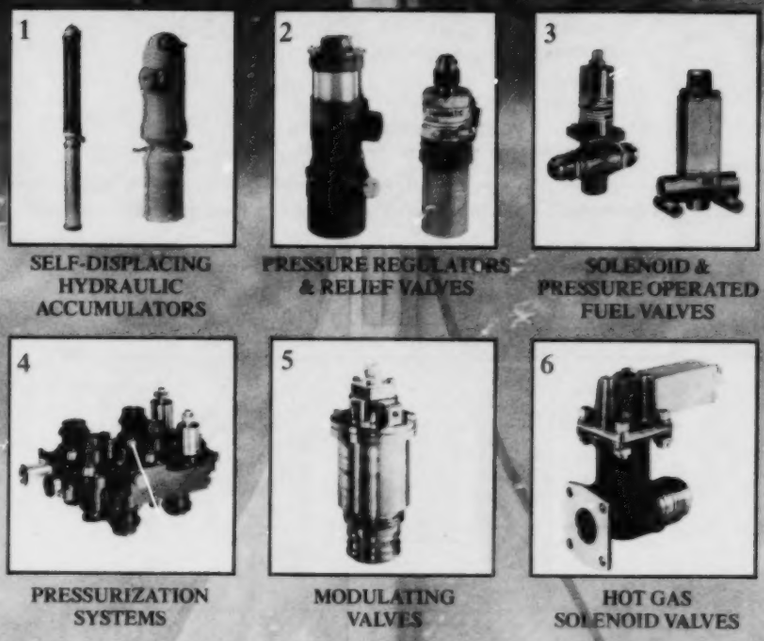

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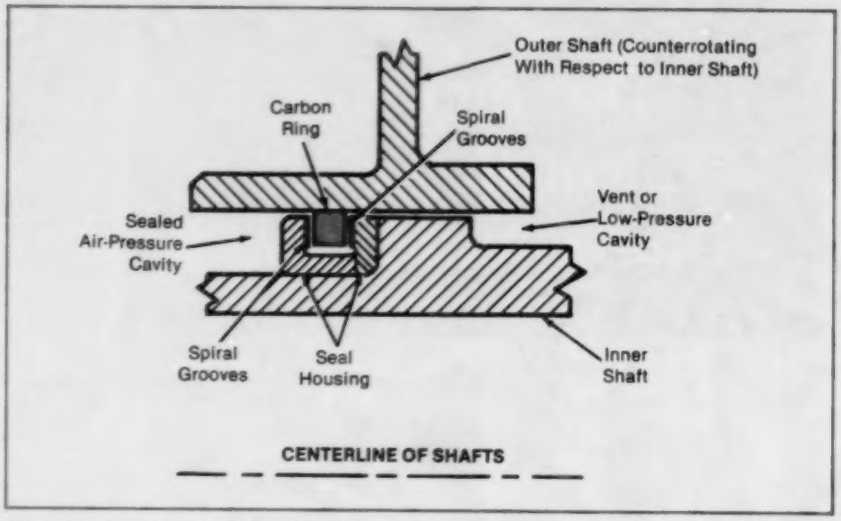

Figure 1. The **Intershaft Seal** includes spiral grooves that generate lubricating gas films.

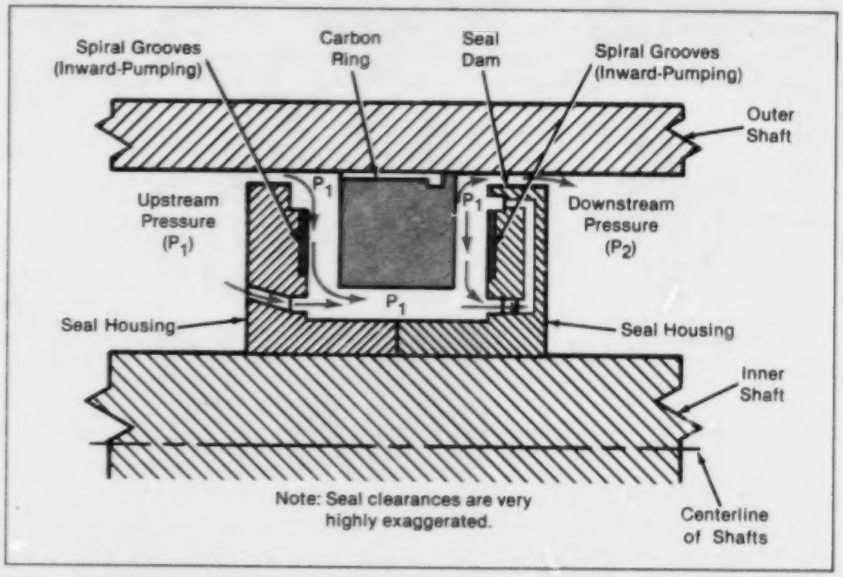

Figure 2. In the **Pressure-Balanced Spiral-Groove Concept,** the spiral-groove flow is isolated from the seal-leakage flow.

which counterrotates with respect to the inner shaft. As the shafts rotate, the carbon ring expands into the outer shaft and assumes the speed of the outer shaft. The relative sliding speed between the carbon ring and the inner shaft can approach 255 meters per second (835 feet per second).

It should be noted that the carbon ring may require a radial split line to limit hoop stresses due to rotation and to assure that the carbon ring will rotate with the outer shaft. Relative axial translations between the inner and outer shafts of up to 0.64 centimeter (0.25 inch) due to thermal expansion are possible over the design operating range. This translation causes the carbon ring to approach one of the two housing faces. The spiral grooves on the housing faces generate a very high lift force as the carbon ring approaches either face, thereby maintaining a fluid film between the carbon ring and the housing face.

Figure 2 is a schematic drawing of the seal showing it in a neutral position (equal clearance on either side of the carbon). The total axial clearance between the carbon ring and the housing face is only 0.0203 millimeter (0.0008 inch) or 0.0102 millimeter (0.004 inch) per side when the seal is centered in the housing. The airflow through the seal is shown; P_1 is the high pressure, and the pressure drop from P_1 to P_2 occurs across the seal dam. The porting shown is designed such that the spiral grooves are bounded by the sealed pressure (P_1) at both the outside and inside diameters; hence, there is no pressure difference across the spiral grooves. This is known as a pressure-balanced spiral-groove concept. The pressure-balanced concept isolates the spiral-groove flow from the seal-leakage flow so that the spiral-groove performance is not subject to any ill effects due to seal-leakage flow.

Transients such as pressure and thermal expansion that occur over the engine-operating range will change the axial-force equilibrium of the seal, thus causing the carbon seal ring to approach one of the housing faces. As the clearance between the carbon seal ring and one of the housing faces approaches zero clearance, the spiral grooves generate a very high lift force. The lift force increases exponentially with reduction in clearance until a clearance is achieved at which axial-force equilibrium is restored. The forces that enter into the axial-force equilibrium are pressure-area forces on the carbon ring, friction force between the carbon ring and the outer shaft (produced by relative axial translations of the shafts), and the lift force generated by the spiral grooves.

This work was done by Eliseo DiRusso of **Lewis Research Center.** *Further information may be found in NASA TP-2142 [N83-25712/NSP], "Design Analysis of a Self-Acting Spiral Groove Ring Seal for Counter-Rotating Shafts" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14248

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Designing Power-Transmission Shafting

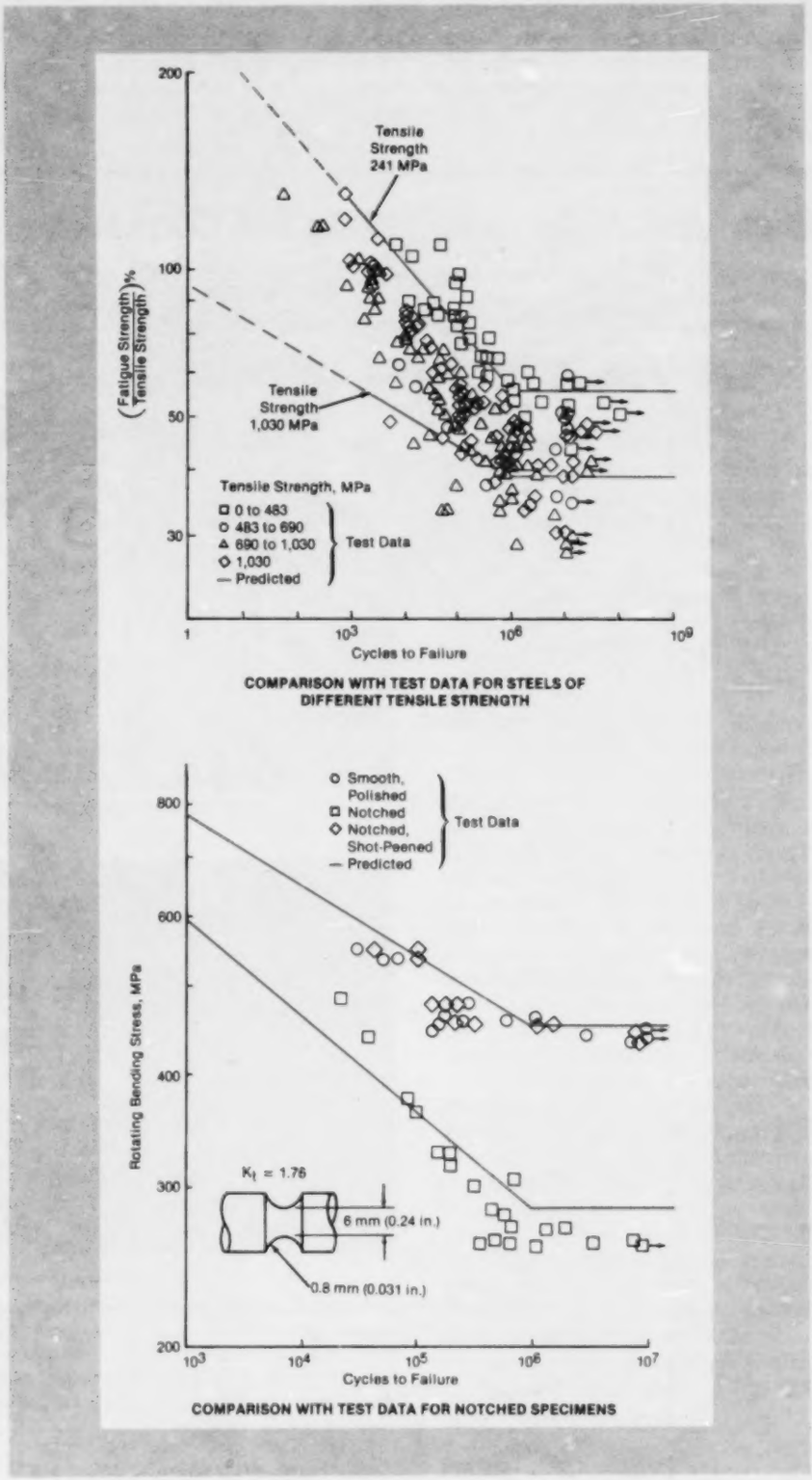
Consideration of stress and fatigue life gives better designs.

Lewis Research Center,
Cleveland, Ohio

Power-transmission shafting is a vital element of all rotating machinery. A shafting-design procedure has been developed based on fatigue-strength considerations. This method not only accounts for the effects of static and constant-amplitude fluctuating loads but will provide shaft-diameter estimates for variable-amplitude-loading duty cycles.

A stress-life approach is adopted for limited-life designs, restricted to the intermediate-to-high cycle-fatigue-life region. A local notch strain-life analysis is recommended for short-lived designs. In the absence of actual component-fatigue data, the S-N (stress-life) characteristics of the shaft in bending can be approximated by a straight line connecting the true fracture-strength coefficient with the corrected fatigue limit of the shaft on log/log coordinates. The figure shows that this approximation works reasonably well for a variety of steels, based on fatigue data found in the open literature. The predictions appearing in these figures are an estimate of the fatigue limit based on the ultimate tensile strength of the steel. Knowledge of the true fatigue limit for the particular steels in question would be expected to enhance the accuracy of the prediction.

The method requires the use of the fatigue limit of the shaft to be designed, which is almost always different from the fatigue limit of the highly-polished, notch-free test specimen, commonly listed in material-property tables. Typical values of fatigue-life-modifying factors are used to correct the fatigue limit of the test specimen for service factors that are known to affect fatigue strength. These factors include surface condition, size, reliability, temperature, stress concentration, press-fitted collars, residual stress, and corrosion corrections. For example, residual stress due to certain manufacturing processes can have major effects (both beneficial and negative) on shaft fatigue life. This is clearly illustrated in the lower part of the figure, which shows that the introduction of compressive residual stress in the notched region of the test specimen through shot peening has essentially eliminated the notch effect almost entirely.



The **Stress/Life Characteristic** of a shaft is approximated for design purposes by straight lines based on previously published data. The straight-line predictions shown here are estimates of the fatigue limit based on the ultimate tensile strength of steels.

Shafting material, rigidity, and critical speed are also considered, as are surface finish, dimensional tolerance, and material-strength properties of commonly-used commercial transmission-line shafting. Recommended gear and bearing maximum-shaft-misalinement values are also addressed. Critical speed considerations are used along with a Rayleigh-Ritz method to calculate, as a first approximation, the fundamental or first critical frequency of a shaft/bearing system using either completely-rigid or laterally-flexible bearing supports.

A longstanding objective in the design of power-transmission shafting is to eliminate excess shaft material without compromising operational reliability. This shafting-design method allows the designer to assess the impact of key operating and design variables and shaft-material selection on fatigue life and shaft size. The method lends itself to the computer-aided design of both aerospace and industrial shafting.

This work was done by Stuart H. Loewenthal of **Lewis Research Center.** *Further information may be found in NASA RP-1123 [N84-27041/NSP], "Design of Power-Transmitting Shafts." [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14240

Locating Cracks Amid Pitting and Corrosion

Use of two fluorescent penetrants reveals cracks.

Lyndon B. Johnson Space Center, Houston, Texas

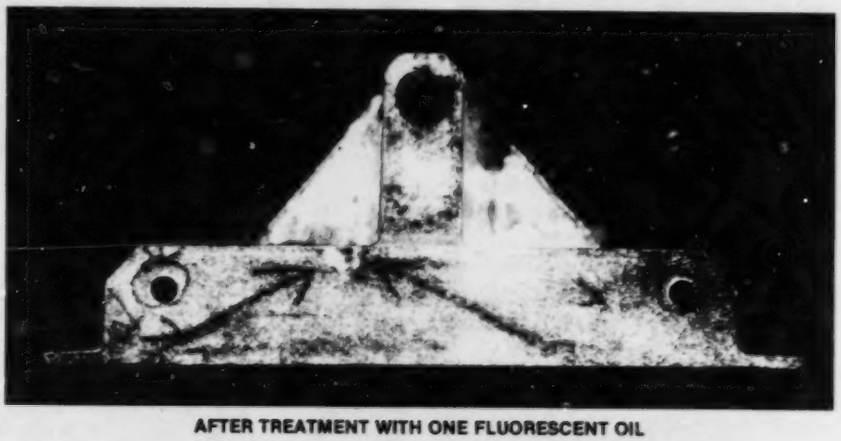
Two fluorescent oils are used in a new inspection technique for locating cracks in metal parts. Use of just one fluorescent oil is not always effective when a part is pitted or corroded. The pits and corroded areas absorb the dye along with the cracks, thus masking fluorescence from the cracks.

A part to be inspected by the two-penetrant technique is first degreased in a solvent vapor, then chemically etched to remove 0.0004 to 0.0006 in. (0.010 to 0.015 mm) of material from the surface. The part is then dried in warm, circulated air at a maximum temperature of 175 °F (79 °C).

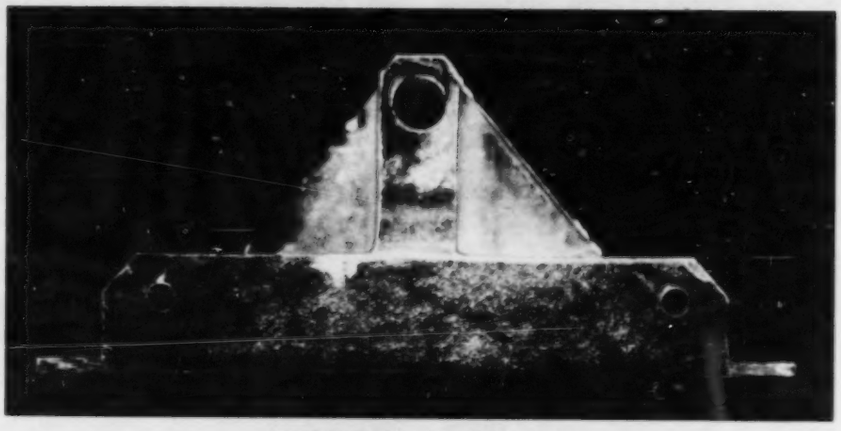
A postemulsifiable fluorescent oil, ZL-30 (or equivalent), is applied to the part and allowed to remain on the surface for 30 min. Then a water-washable fluorescent oil, ZL-17 (or equivalent) is applied and the excess allowed to drain off. The water-washable oil emulsifies the postemulsifiable oil on the surface so that it can be removed from the surface by a water rinse, even from the pitted and corroded areas. However, the postemulsifiable oil embedded in deep, fine cracks remains.

The water rinse is done under ultraviolet light. The part is then immersed in an aqueous solution of developer ZP-13A (or equivalent), drained, dried in air at 175 °F (79 °C) maximum, then cooled below 100 °F (38 °C). After waiting at least 15 min for development (but no longer than 75 min), the part is examined in ultraviolet light. Fluorescent dye retained by cracks is readily visible and distinguishable from the minimal fluorescence retained by pitted and corroded material (see figure).

The dual-dye technique has been used to inspect metal parts having surface-roughness-height ratings from 125 to 450 μin. (3.2 to 11.4 μm). The parts have included shot-peened machined aluminum extrusions; partially machined aluminum castings; aluminum, steel, and titanium tabular weldments; aircraft landing-gear components; chemically milled aluminum sheet and extrusions; and rough-machined aluminum and steel forgings. It has also been used on nonporous ceramic parts.



AFTER TREATMENT WITH ONE FLUORESCENT OIL



AFTER THE DUAL-OIL TREATMENT

This Machined Aluminum Fitting has extensive pitting and areas of corrosion that retain fluorescent penetrating oil. In the upper photograph, the fluorescence from these areas obscures fluorescence from oil absorbed by cracks. After treatment with a second, emulsifying oil, much of the fluorescence from pitted and corroded areas disappears and, as shown in the lower photograph, fatigue cracks emanating from holes become evident.

This work was done by Peter P. Fahey of Fairchild Republic Co. for **Johnson Space Center.** *For further information, Circle 69 on the TSP Request Card. MSC-20311.*

Eliminating Thermal Cracks in Flange/Duct Joints

Heat and pressure during bonding allow joints to accommodate expansion.

Lyndon B. Johnson Space Center, Houston, Texas

An improved technique for attaching an aluminum flange to an aramid/epoxy duct prevents the subsequent development of cracks in the joint during thermal stress. Previously, the flange was bonded to the outside surface of the duct (see Figure 1). In service, leaks occurred at the bond line when temperature and pressure rose. The attachment method made no allowance for the differing thermal expansion rates of aluminum and aramid/epoxy.

In the new method, the flange is butted against the cylindrical mold on which the duct is to be fabricated. The flange has a tapered neck so that it will nest in the duct opening. The epoxy-impregnated aramid tape is wrapped around the mold so that the tape overlaps the flange (see Figure 2). While the tape is being wrapped, pressure is applied to it and the inside of the flange as they are heated uniformly to the maximum expected operating temperature. The heat and pressure are maintained until the aramid/epoxy laminations have cured.

The new method produces reliable bonds. Flanged ducts have been tested at temperatures ranging from −150 to +350 °F (−100 to +180 °C) and pressures of up to 100 lb/in.^{2} gauge (790 kPa) through 100 cycles without flange/duct separation.

This work was done by James E. Adams of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 46 on the TSP Request Card.*
MSC-20833

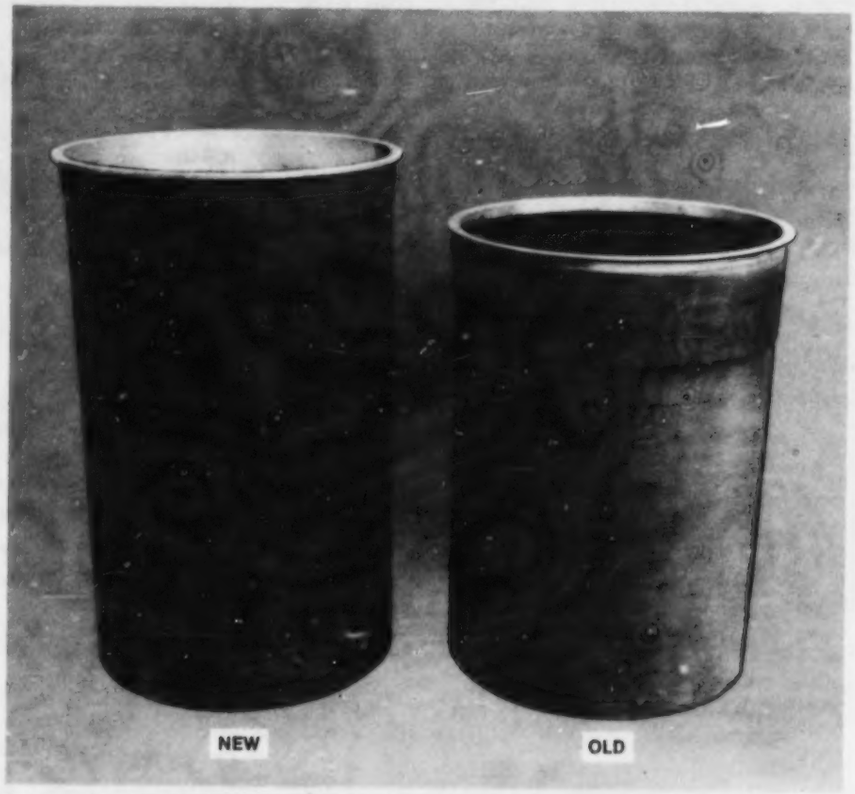


Figure 1. In the **Older Design** (right), the flange was slid onto the duct, and additional layers of aramid/epoxy duct material were wound to form the joint. In the new design (left), the duct is wound onto the flange.

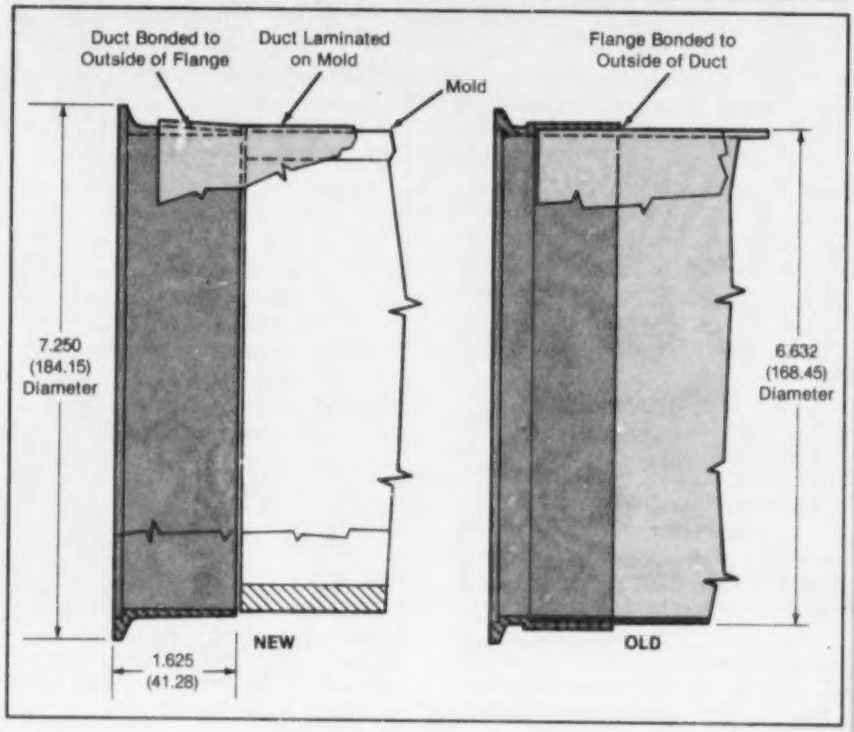


Figure 2. The **New Configuration for Bonding** a flange to a duct allows for the large difference in thermal expansion between aluminum and aramid/epoxy. The old configuration, in contrast, cracked at the joint between the two parts. Dimensions are in inches (millimeters).

Adapting Inspection Data for Computer Numerical Control

Machining time for repetitive tasks is reduced.

Marshall Space Flight Center, Alabama

A program for a computer-numerical-control jig boring machine ensures that holes are drilled and reamed with high accuracy in post stubs on the main injector body of the Space Shuttle main engine. Although the post stubs are positioned so that they may deviate from the design position by as much as 0.025 inch (0.635 millimeter), the program controls the hole positions to within 0.010 inch (0.254 millimeter) of the design positions. With modifications this approach should be applicable to the machining of many precise holes on large machine frames and similar objects.

The program converts measurements of stub post locations by a coordinate-measuring machine into a form that can be used by the numerical-control computer. The work time is thus reduced by 10 to 15 minutes for each post. Since there are 600 such posts on each injector, the time saved per injector is 100 to 150 hours.

This work was done by Everett E. Hutchison of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29117

Non-Back-Drivable, Freewheeling Coupling

Cables can be reeled in and out with less risk of tangling.

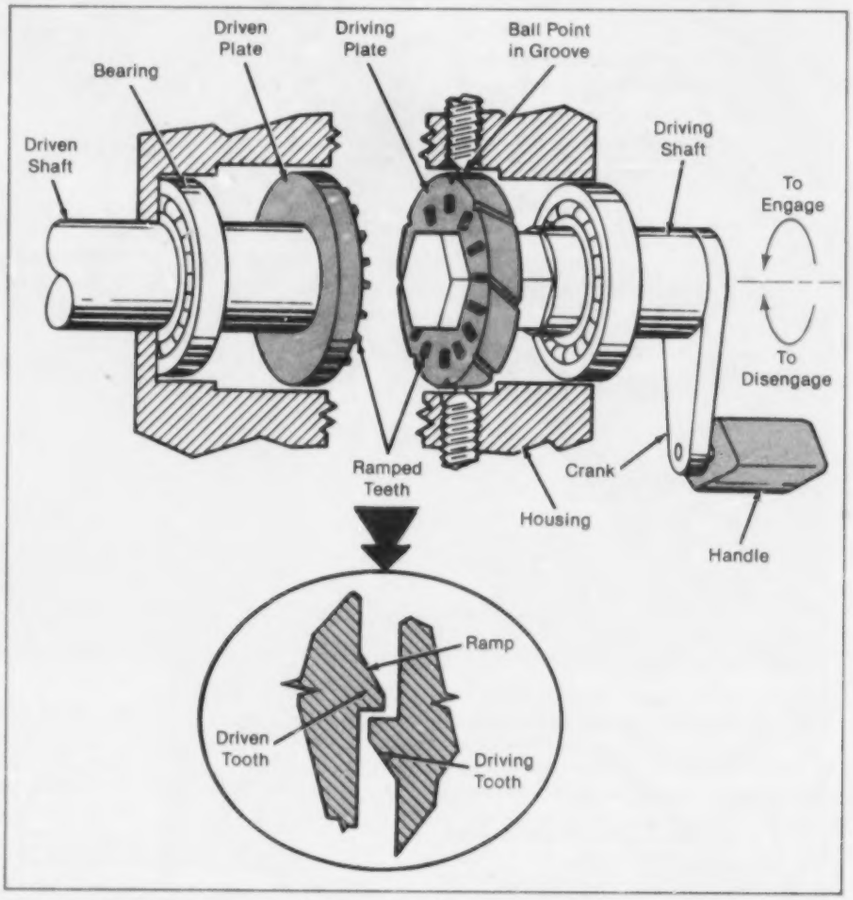
Lyndon B. Johnson Space Center, Houston, Texas

An overrunning clutch transmits forward rotary power from a driving unit (for example, a motor or a hand crank) but does not allow the driven unit to transmit power to the driver. The clutch allows the driven unit to turn freely forward faster than the driver; that is, to freewheel. If the driven unit reverses its direction of rotation, the clutch disengages the driving and driven units, allowing reverse freewheeling.

The clutch contains a driving plate and a driven plate on separate coaxial shafts (see figure). The opposing faces of the plates hold ramp-shaped (ratcheting) teeth. The driven plate is fixed to its shaft, but the driving plate is splined on its inside circumference and is free to slide axially on the splined driving shaft. The driving plate has helical grooves in its outside circumference; ball-point screws in the housing around the driving plate ride in these grooves.

When the hand crank (or motor) turns the driving plate in the forward direction (counterclockwise in the figure) faster than the driven plate, the ball points engage the helical grooves, moving the driving plate against the driven plate and engaging the teeth. The driving plate then transmits power to the driven plate through the engaged teeth.

When the clutch is engaged, but not transmitting power, and the driven side rotates forward faster than the driving plate, the ramped teeth push the plates



Opposing Teeth Engage with clockwise rotation and disengage with clockwise rotation of the crank. The driving plate moves axially with respect to the driven plate on ball points to engage and disengage.

The Inland Motor Team Philosophy: Demanding Applications Require Servo Components That Are Complementary—And Uncompromising.

At Inland Motor we specialize in finding solutions to difficult motion control problems. That's why we have pioneered the development of servo systems comprised of fully compatible, complementary servo components. By supplying motors, amps and tachs that are designed to work together without compromise, we're able to deliver "systems" that are not only ideally suited for your application but remarkably obedient.

Building Smart One Block At A Time

The system illustrated in Figure 1 is a simplified example of a high-performance single axis dc servo system. The diagram illustrates our commitment to providing a tailored solution to each of your motion control requirements. Inland Motor designs and manufactures brushless and brush-type motors in both frameless and housed configurations, as well as a full line of PWM servo amplifiers. Once the dynamic and environmental constraints (such as torque, speed, duty cycle, envelope, ambient temperature, precision, etc.) have been identified, we can then specify or develop a motor suited to those requirements.

Once parameters are established, an amplifier is sized for your application. Motor control requirements, such as voltage and current, can be matched through winding changes to any of several pulse-width-modulated (PWM) amplifiers manufactured by Inland Motor. Finally, a power supply and transformer can be selected to complement your amplifier.

Our Frameless Motors Eliminate Backlash

Most of our existing motor and tachometer designs are "frameless, direct-drive" configurations. This means that unwanted backlash associated with gears and belts is eliminated. You receive the full benefit of a motor (available peak torques range from 1 oz. in. to 1,000,000 oz. in.) that is an integral part of your machine, relying on existing bearings and shaft structure for support. And, because direct-drive is not suitable for every application, we offer housed motors and tachs as well.

Servo Amps With No Room For Compromise

Our PWM servo amps are available in many configurations to suit a variety of applications. Each model has an internal, high bandwidth current loop as its foundation. Current loops are what dc motors respond to best, so that's where we have concentrated our efforts. Around the inner current loop, we offer features such as velocity control (analog and digital), phase-locked loops and position loops. Our PWM servo amps operate at inaudible frequencies of 20 kHz or higher, are 90% efficient, need no cooling fans and come in a small modular package size.

When you purchase a complementary motor and amp from Inland, we compensate the amp to the motor and deliver a current loop Bode plot for the combination.

In addition, we offer power supplies that provide the appropriate dc voltage and current to run our PWM amplifiers from a single-phase ac source. These units handle power sequencing and absorb regenerative energy as required.

Together, our servo amps and power supplies combine to maximize your motor's performance, not compromise it.

Send Us Your Most Un-Controllable Problems

We speak of the "Inland Motor Team Philosophy" because it's a team of people—not a particular product—that lies at the heart of our company. When you call the Specialty Products Group for assistance, you'll be connecting with engineers committed to finding solutions for your one-of-a-kind application problems. That's why site visits are often arranged so we can discuss your project in detail. We think our team is quite talented. But, what most distinguishes the Group is our determination to be responsive—to be a team that adapts, tests and refines our components until we can deliver you true motion control solutions.

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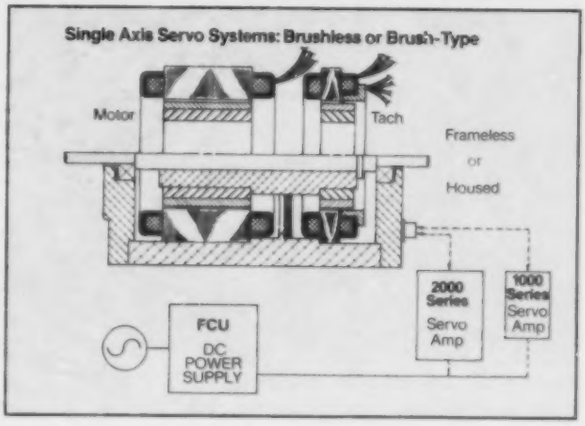

INLAND MOTOR
KOLLMORGEN CORPORATION
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501 First St. Radford, VA 24141
703/639-9045 TWX: 710-875-3740

Circle Reader Action No. 423

apart. The driven plate then turns independently.

When the clutch is engaged and the driven side starts to turn backward (clockwise in the figure), the teeth rotate the driving plate backward only briefly; the driving plate slides on its grooves until the teeth disengage. No further motion is transmitted from the driven plate to the driver.

The clutch was developed for reeling and unreeling a tether line used to link an astronaut to a space vehicle. It allows the line to be pulled out freely and helps to prevent the line from tangling in the reel housing when the crank is turned backward. The new clutch concept may also be applicable to fishing reels, toys, and safety-line mechanisms.

This work was done by W. R. Llewellin of Martin Marietta Corp. for **Johnson Space Center.** *For further information, Circle 86 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20475.

Effects of Gear-Cutter Geometry on Performance

Bending stress is reduced by improving tooth-fillet design.

Lewis Research Center, Cleveland, Ohio

Aircraft gas-turbine engines generally operate at shaft speeds ranging from 10,000 to 30,000 rpm. To harness this power and to reduce the engine speed to the desired rpm, the power-transmission industry has been developing high-performance power-transmission systems. A recently completed research addressed the gear-tooth geometry and explored how various design parameters affect gear-tooth bending strength, compressive strength, noise, and vibration.

It was demonstrated and verified, using mechanical and computer models, that gear-cutter geometry has a significant impact on the calculated bending stresses. Using the optimized gear-cutter design technology of this work, the gear designer can reduce the bending stresses by up to 20 percent. This reduction in bending stress is a result of the improved geometry of the tooth fillet, which, in turn, results in a significant improvement in horsepower-per-pound ratio. The results of this work can be summarized as follows:

- A definite relationship exists between the pitting resistance and bending strength of gear teeth. This relationship is controlled by the selected allowable compressive and bending stresses. For high-quality aircraft-type gearing, the various modifying factors used to calculate working stresses have no effect on the relationship between pitting resistance and bending strength, although they may affect the selection of the allowable stresses. The balancing of gear-tooth designs for pitting resistance and bending strength can thereby be accomplished by manipulation of the geometry factors "I" and "J" for pitting resistance and bending strength, respectively.
- Using the new AGMA Standard 218.01 as a guide, computer programs for calculating gear-tooth geometry factors "I" and "J" and the mechanical model of the gear-tooth generating machine have been shown to be valid tools for determining geometry factors for modified gear-tooth forms.
- For AGMA standard long/short addendum; i.e., pinion addendum equal to 125 percent of standard and gear addendum equal to 75 percent standard, pitting resistance tends to control the design of external meshes, and bending strength tends to control the design of internal meshes.
- Significant changes in gear-tooth geometry factors "I" and "J" can result when certain gear-tooth design parameters are varied. Increases in the values of "I" and "J" represent increased capacity for the gear mesh. During this work, one parameter was varied as others were held constant. At a gear ratio of 2.5 to 1, the table summarizes some approximate effects on pinion "I" and "J" as the noted parameters are varied. Improvements in "I" and "J" tend to peak in the range between 15° and 20° for helix-angle variation. Improvement in "I" as listed is for a 15° helix angle.
- In light of the increases which can be accomplished in geometry factors, a transmission design rated at 450 hp (340 kW) could be uprated to 525 to 550 hp (390 to 410 kW) using improved gear-tooth-geometry, high-contact-ratio

PARAMETER VARIATIONS	I	J
Addendum $\frac{1.00}{P_d}$ to $\frac{1.50}{P_d}$	Increase 20%	Increase 45%
Dedendum $\frac{1.40}{P_d}$ to $\frac{1.15}{P_d}$	No Effect	Increase 15%
Pressure Angle 18.5° to 25°	Increase 20%	Increase 35%
Helix Angle 0° to 20°	Increase 50%	Increase 38%
Face-to-Diameter Ratio 0.4 to 1.1	Increase 21%	Increase 50%

The Gear-Tooth Geometry Factors "I" and "J" for pitting resistance and bending strength, respectively, are increased by changing the geometry of the tooth fillet.

helical gears of the same size and weight. These gears should run quieter and smoother than the spur-gear system.

This work was done by Dezi Folenta of Transmission Technology Co., Inc., for **Lewis Research Center.** *Further information may be found in "Study of Gear Geometry/High Contact Ratio Affecting High Performance Helicopter Transmissions." To obtain a copy, Circle 16 on the TSP Request Card. LEW-14243*

High-Speed Propeller for Aircraft

Engine efficiency will be increased.

Lewis Research Center, Cleveland, Ohio

The advanced high-speed propeller (propfan) extends the cruise speed of conventional turboprop systems from the 0.5- to 0.6-mach range to the mach-0.8 speed range of today's turbofan-powered aircraft. Compared to turbofans, however, the propfan offers a substantial improvement in propulsive efficiency. Fuel savings over advanced high-bypass-ratio turbofan systems are estimated to be 15 to 20 percent (30 to 50 percent over current turbofan systems). Had the domestic fleet of B727, B737, and DC-9 aircraft been replaced with propfan engines in 1981, a total of 3 billion gallons (1×10^7 m^3) of fuel would have been saved. Examples of propfan-powered transport-aircraft concepts are shown in Figure 1.

The major features of an advanced high-speed turboprop propulsion system are shown in Figure 2. The propeller blades themselves are required to be quite thin and highly swept to minimize compressibility losses and propeller noise during high-speed cruise. The use of 8 or 10 blades with a high-propeller-power loading allows overall propeller diameter to be kept relatively small.

An area-ruled spinner and integrated nacelle shape reduce compressibility losses in the propeller hub region. Finally, a large modern turboshaft engine and gearbox provide power to the advanced propeller.

The propfan system is adaptable to a number of applications, such as high-speed (subsonic) business and general-aviation aircraft, and military aircraft including V/STOL.

This work was done by David A. Sagerser of **Lewis Research Center** *and Bernard S. Gatzen of Div. of United Technologies Inc. Further information may be found in NASA TM-83736, [N84-29878/NSP], "Fuel Savings Potential of the NASA Advanced Turboprop Program" [$10]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LEW-14241

Figure 1. **Typical Transport Airplanes** are shown equipped with the new high-speed propellers.

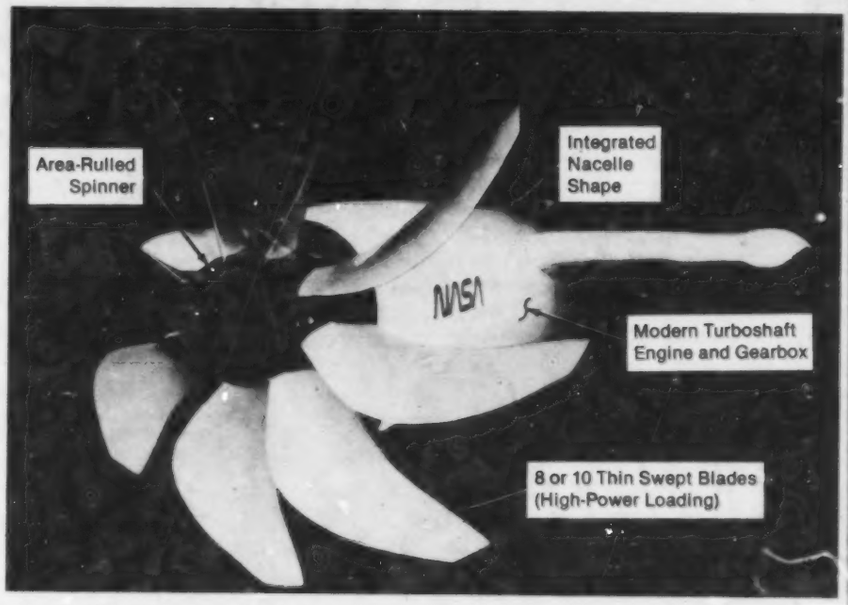

Figure 2. The **Advanced High-Speed Turboprop System,** with the design features indicated here, will increase efficiency. Fuel savings of 30 to 50 percent over present systems are anticipated.

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Circle Reader Action No. 300

Pump for Saturated Liquids

Boiling liquids would be pumped by a device based on proven components.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed pump is designed to handle boiling liquids. Conventional liquid pumps do not accept liquids at their saturation, or boiling, pressures. The proposed pump would make it unnecessary to pressurize cryogenic liquids in order to pump them. The problems of introducing a noncondensable pressurizing gas could be avoided.

According to the two-phase pumping concept, the saturated liquid flows from a tank to a two-phase nozzle, in which it flashes into a liquid/vapor mixture and impinges on an inclined-plate separator (see figure). The separated liquid flows through a diffuser to a discharge conduit. The separated vapor is compressed and returned to the tank.

If the nozzle, separator, and diffuser have high enough efficiencies and if the nozzle-exit pressure is low enough, the liquid will discharge at a higher pressure than it had in the tank. In addition, it will be cooled to the saturation temperature corresponding to the nozzle-exit pressure.

The two-phase pump, then, produces two important changes: It raises the pressure of the liquid from the tank pressure to a higher discharge pressure, and it creates a net positive-suction head equal to the difference between the discharge pressure and the nozzle-exit pressure. The suction head is a result of both the pressure rise and the temperature drop of the liquid.

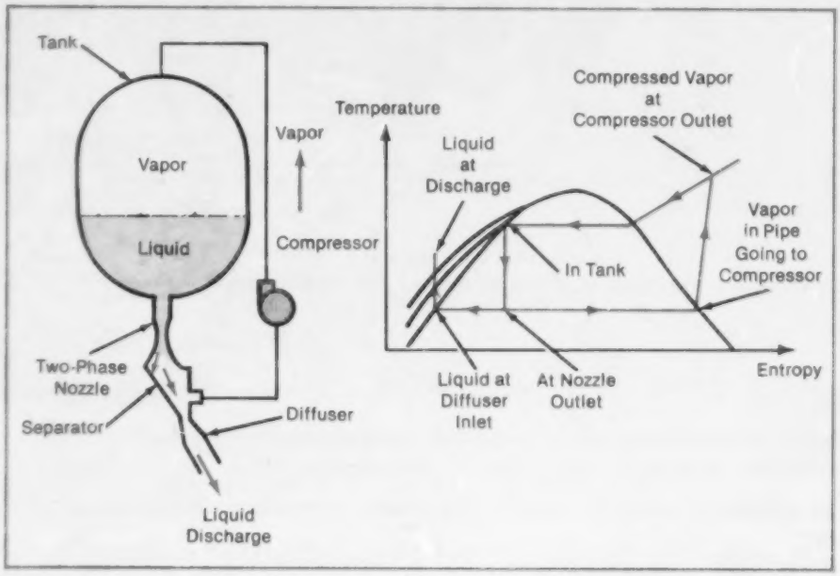
Even though the liquid is discharged at a temperature lower than that in the tank, there is no net cooling in the pump: On the contrary, there is net heating. The vapor returned to the tank contains the heat removed from the discharged liquid plus the heat from the compressor.

The pump would use the same combination of the two-phase nozzle, separator, and diffuser that were previously used in jet pumps and in liquid-metal magnetohydrodynamics. In those applications, the energy of the liquid leaving the separator was used to do pumping work or electrical work before the liquid entered the diffuser.

Calculations based on representative efficiencies for the nozzle, separator, diffuser, and compressor show that the two-phase pump would perform well. For example, with a tank pressure of 18 lb/in.^{2} (124 kPa) and a nozzle-exit pressure of 5 lb/in.^{2} (35 kPa), it would pump liquid hydrogen to a discharge pressure of 27 lb/in.^{2} (186 kPa). (Pressures are absolute values.)

The two-phase pump is especially attractive for transferring cryogenic liquids from one tank to another. In such transfers, the combination of pressure rise and liquid cooling permits transferring the liquid without venting the receiver tank, thus preventing loss of fluid.

This work was done by David G. Elliott of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 10 on the TSP Request Card.*
NPO-16152



Expanding a Saturated Liquid in a nozzle and diverting its phases along separate paths in a liquid/vapor separator raises the pressure of the liquid. The liquid is cooled in the process.

Receptacle for Optical-Fiber Scraps

Small pieces of glass are trapped by moving air.

John F. Kennedy Space Center, Florida

A safety device holds small scraps of glass optical fibers until disposal. The scraps are cleaved and broken pieces produced during splicing and other manufacturing operations. These scraps are hazardous: Made of clear glass and typically only 125 μm in diameter, they penetrate the skin easily and are difficult to see to remove. Previously, the pieces were stored until disposal on the adhesive sides of tape strips. However, the scraps are extremely light in weight and do not adhere well; after the tape becomes loaded, additional fibers do not contact the adhesive.

The device (see figure) traps the fibers in

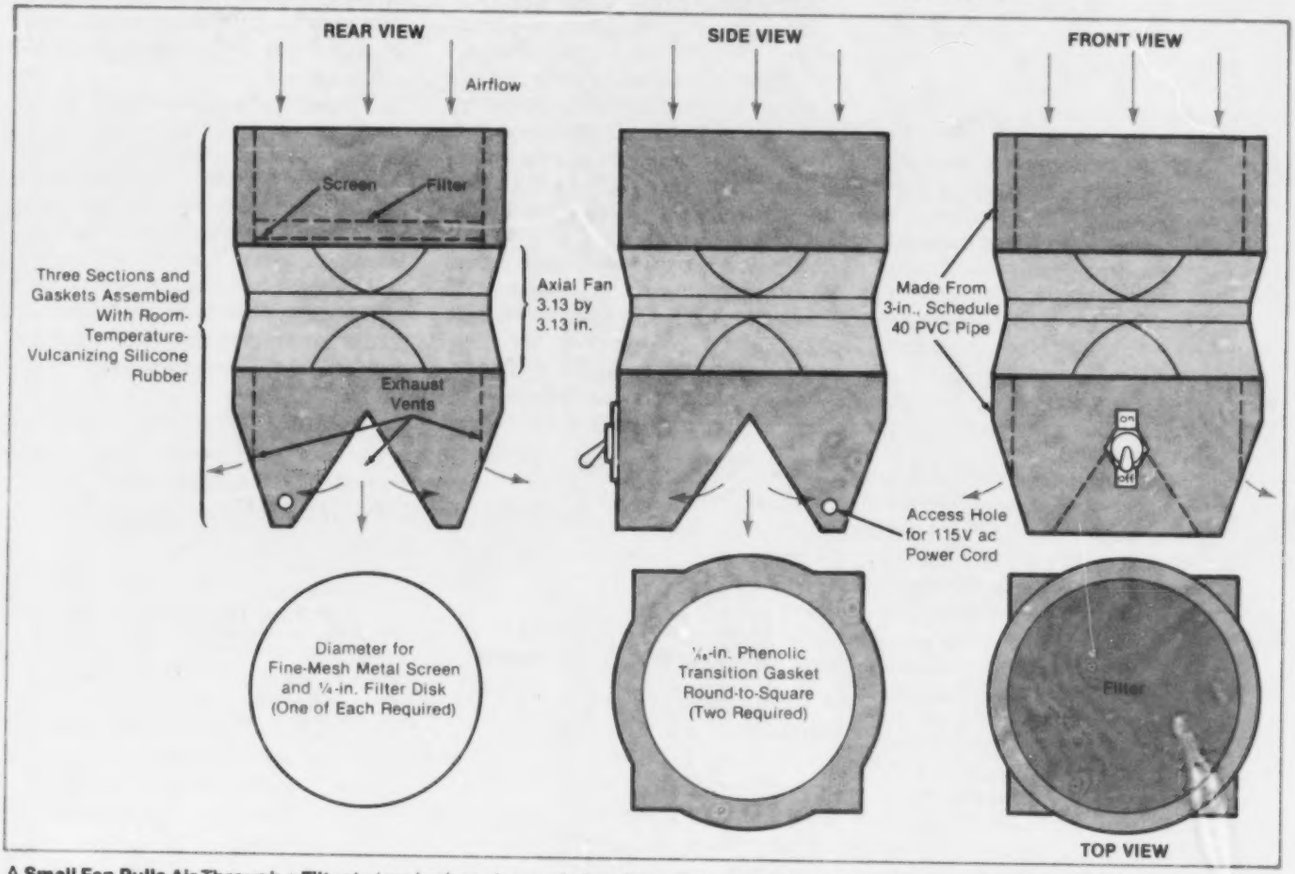
a section of black air-conditioner filter material. The filter section rests on a metal screen above an axial fan, which pulls air down through the filter. The fan is a small, quiet unit of a type ordinarily used to cool electronic equipment.

The filter is held in a section of polyvinyl chloride (PVC) pipe having a diameter of 3 in. (7.6 cm). Air is exhausted through triangular gaps cut in the bottom of a similar piece of pipe below the motor. Phenolic transition gaskets are placed between the round pipe and the motor, which has a square outline. Although round pipe was used to construct the prototype units, square pipe could also be used, thereby eliminating the need for the transition gaskets.

During manufacturing operations, the fiber scraps are dropped on the filter with tweezers. The moving air retains the fibers in the filter. The filter is lifted out to dispose of the fiber scraps, then replaced in the unit. As an added benefit, the exhaust from the bottom of the unit is convenient for drying fibers that have been cleaned in acetone.

This work was done by R. O. Nevin of Lockheed Space Operations Co. for **Kennedy Space Center.** *No further documentation is available.*

Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11326.



A Small Fan Pulls Air Through a Filter to trap broken pieces of glass fiber. The unit is inexpensive and assembled from readily available parts.

Thermally-Integrated Fuel-Cell/Electrolyzer Systems

The design is less complex and more reliable than prior designs.

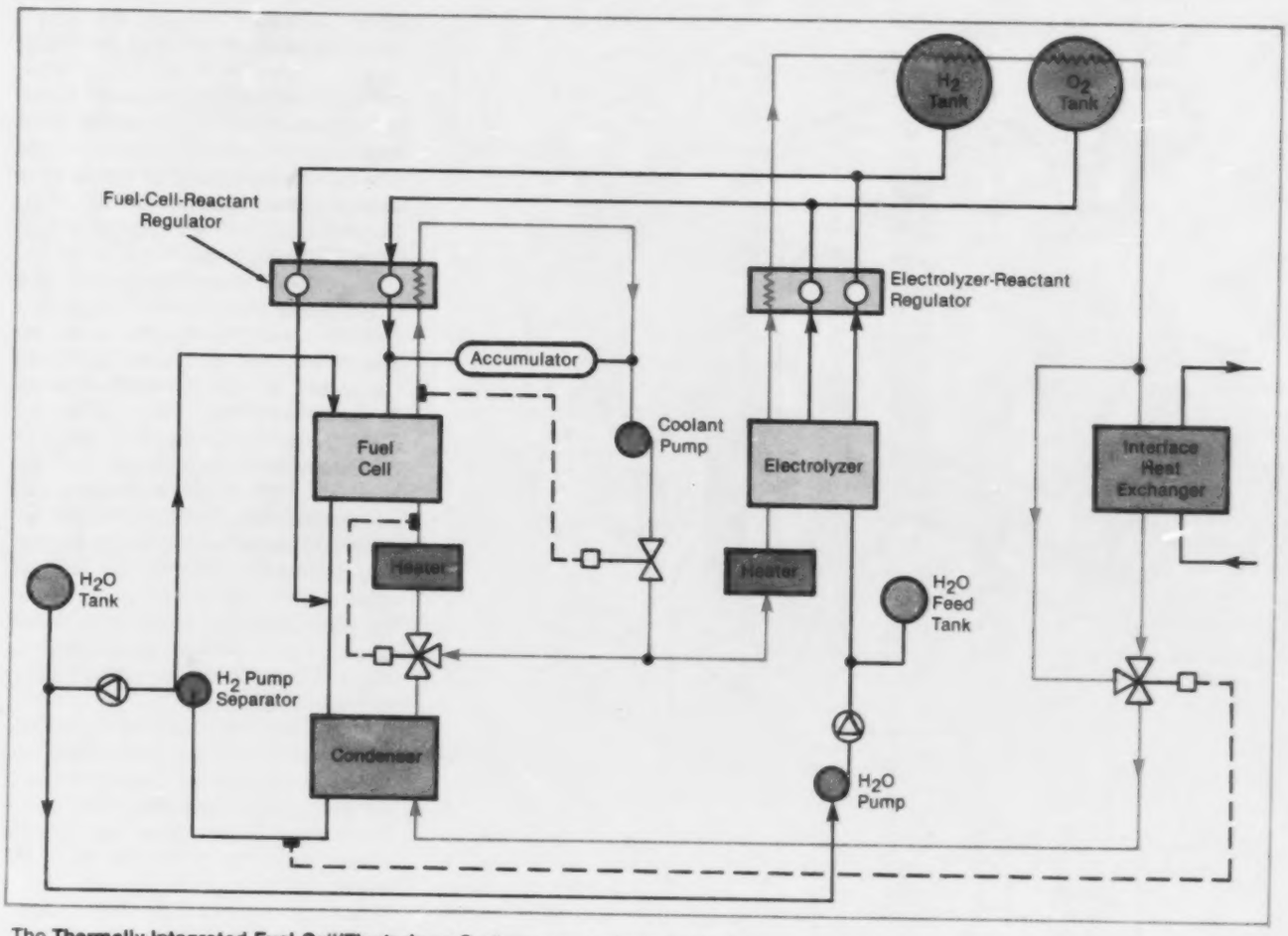
Lewis Research Center, Cleveland, Ohio

A new and more efficient method of thermally integrating a fuel cell and an electrolyzer has been designed. This design addresses the thermal integration of a fuel cell and a water electrolyzer in a regenerative fuel-cell system.

Since the operation of the regenerative fuel-cell system involves the alternate activation of the fuel cell and the electrolyzer, the individual cells must be cooled while they are operating, and then heated, while idle, to maintain them at operating temperature. Previous system concepts had a coolant loop for each stack with a heat exchanger between them for the required heat transfer. This is a system configuration (see figure) that provides this thermal integration with a single coolant loop. This configuration does not have the thermal limitations associated with trying to transfer heat between two coolant loops.

A single-loop system has the benefit of fewer components than a two-loop system, and therefore is less complex and more reliable. This is adaptable to stand-alone power systems in conjunction with solar panels for remote-area applications.

This work was done by J. Garow, K. Michaels, and R. Martin of United Technologies Corp. for **Lewis Research Center.** *No further documentation is available.*
LEW-14235



The **Thermally-Integrated Fuel-Cell/Electrolyzer System** uses a single coolant loop.

Hydraulic Actuator for Ganged Control Rods

One device moves multiple elements synchronously.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed hydraulic actuator would move several nuclear-reactor control rods in unison. The actuator would be simpler than a single electric-motor mechanism for operating the ganged rods. It would not only be simpler, lighter, and more compact than individual rod actuators but would also be easier to synchronize. Conceived for use aboard spacecraft, the actuator principle could be applied to terrestrial hydraulic machinery involving the motion of ganged rods.

The actuator would ensure that the control rods are inserted in the reactor during launch, that they are withdrawn when the reactor is in space, and that they re-enter the reactor, when necessary, if the system malfunctions. The actuator thus would prevent the reactor from going critical if the spacecraft should fall into a body of water after an aborted launch. It would then allow the reactor to start producing power when the spacecraft is safely started on its mission and would interrupt power generation in an emergency.

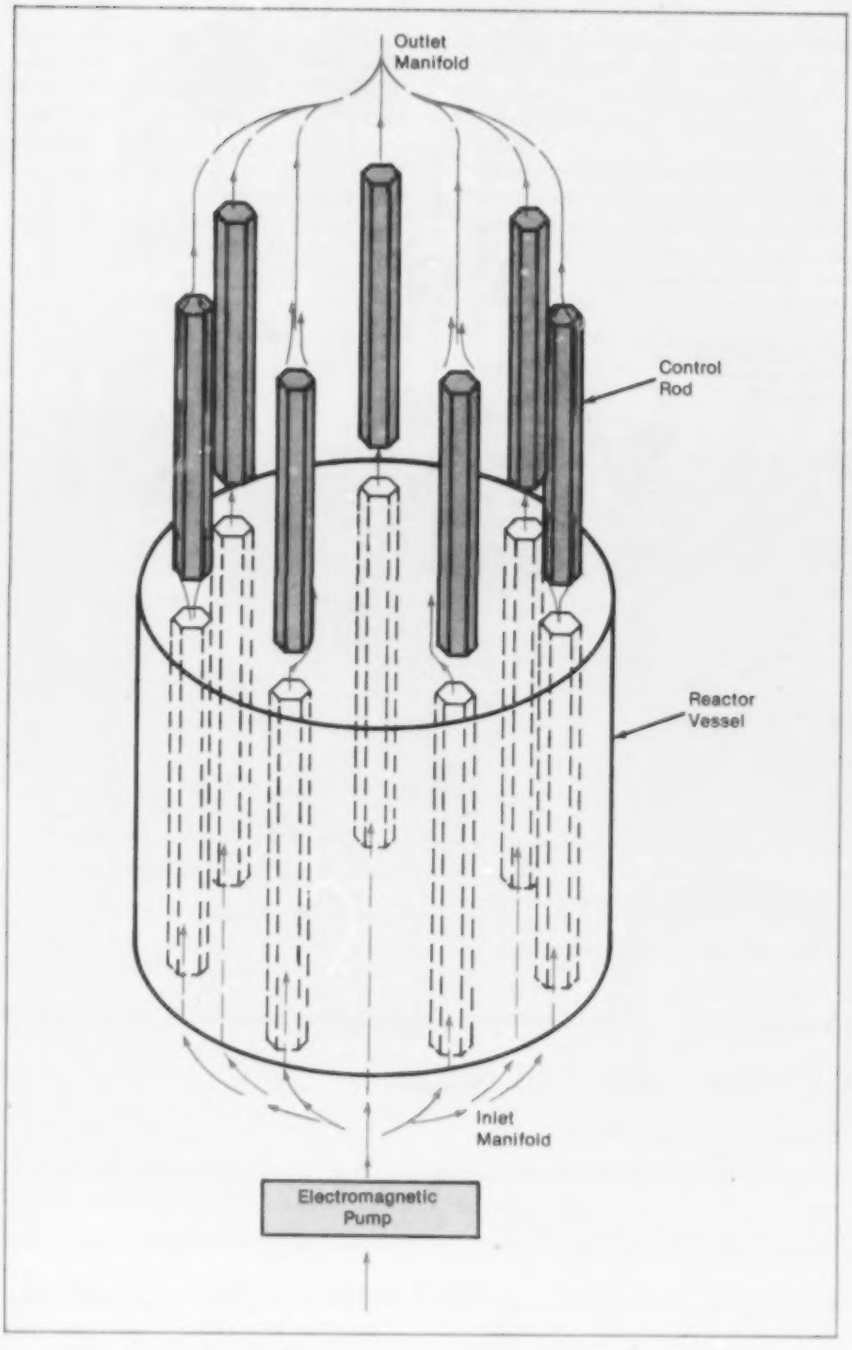
The conceptual actuator consists of an electromagnetic pump and a set of seven hexagonal tubes, one tube surrounding each of the hexagonal control rods (see figure). Depending on the direction of flow, liquid lithium forced through the tubes by the pump provides the pressure to push the tubes out of the reactor, to maintain them out of the reactor, and to return them to the reactor.

When the reactor is turned off, the rods are within the core and are mechanically held there against inertial forces. The electromagnetic pump does not operate at that time. The lithium in the tubes and pump is kept liquid by the heat transferred to it from an auxiliary radioisotope thermoelectric generator.

When the time comes to start up the reactor, the auxiliary power source drives the electromagnetic pump, which builds up pressure against the ends of the rods in the reactor. The pressure overcomes the mechanical rod restraints and moves the rods out of the reactor. The reactor then develops a self-sustaining reaction.

The rods are held in their withdrawn position by the force of the flowing lithium. In zero gravity, this force could be low.

To shut the reactor, the direction of the electromagnetic pump is reversed. The lithium, now flowing in the opposite direction, pushes the rods back into the reactor and holds them there. The rods



The **Electromagnetic Pump** pushes liquid lithium against the ends of control rods, forcing them out of or into the nuclear reactor. Color arrows show the lithium flow for reactor startup and operation. The flow is reversed for shutdown.

inhibit the nuclear reaction and reduce the reactor output to below the critical level.

The flowing lithium performs an additional function: Besides operating the rods, it removes heat from the reactor, thereby helping to keep its temperature at the required value. The lithium cools the reactor in both the forward and reverse directions of flow.

The lithium enters the reactor by a single pipe and leaves it by a single pipe. Inside the reactor, a manifold divides the lithium flow into the seven control-rod tubes, and a second manifold recombines the tube flows into a single exit flow. The fact that the individual pipe flows may be slightly different and that the rods may therefore be moved at slightly different speeds, does not adversely affect the shutdown operation. The system is designed so that the slowest rod is fast enough. Moreover, as the rods seat, the flow in their tubes drops, and more pressure becomes available to drive the remaining moving rods more rapidly.

This work was done by Dennis C. Thompson and Robert M. Robey of Westinghouse Electric Corp. for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 14 on the TSP Request Card.*
NPO-16503

Ignition System for Gaseous Propellants

A spark plug in a fuel-injection manifold resists corrosion and allows efficient combustor cooling.

Marshall Space Flight Center, Alabama

Installation of the spark plug in the fuel-injection manifold of a coaxial injector (see figure) promotes a more efficient cooling of combustor walls in rocket and turbine engines. The spark plug is not subjected to the erosion and contamination that occur in the combustion chamber.

Simple in concept and inexpensive, spark discharge reliably ignites gaseous fuels, especially gaseous hydrogen with gaseous or liquid oxygen. Normally a spark plug is placed so that its tip is at the combustor wall far enough downstream of the injector face to be exposed to partially or fully mixed gases. The exposure to combustion temperatures causes erosion of the uncooled plug. When the com-

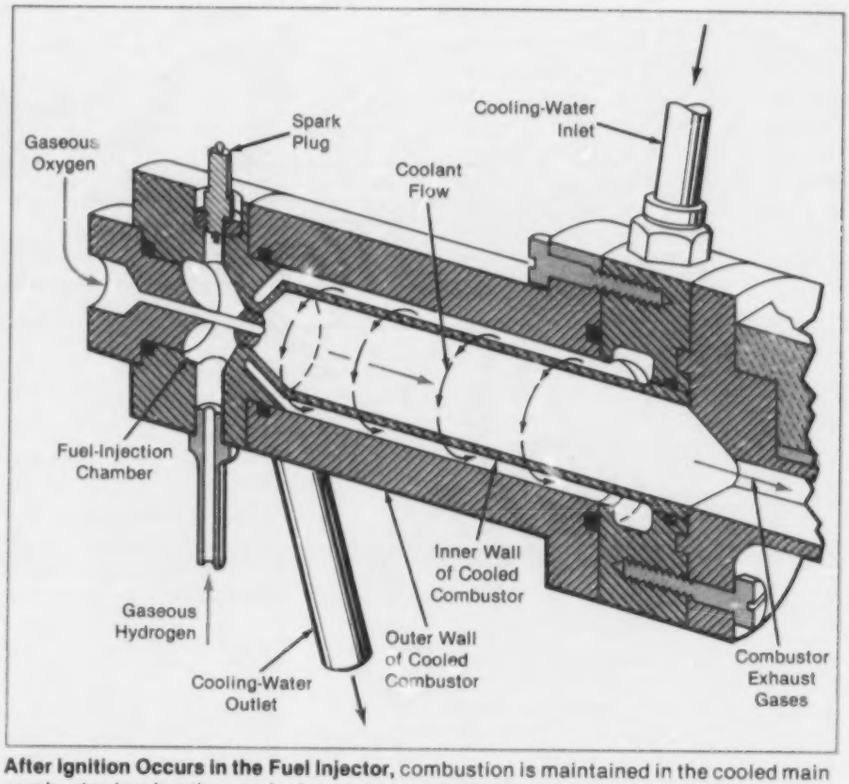
bustor walls must be cooled by a fluid, the presence of the spark-plug port impedes the effectiveness of the coolant.

With the spark plug located in the fuel-injection manifold, the ignition sequence begins with the introduction of gaseous oxygen through the central oxygen tube at the main operating flow rate, followed by sparking and the introduction of gaseous hydrogen through an entry port in the side of the fuel-injection manifold.

At first, gaseous oxygen fills both the combustor and the fuel-injection manifold. When the main fuel valve is opened, the hydrogen mixes with the oxygen and purges it from the fuel-injection manifold. During this expulsion, ignition occurs when an interface of mixed flammable gases passes across the spark discharge. Then the flaming interface of mixed gases, with gaseous oxygen being pushed ahead of it and with gaseous hydrogen following it, passes from the fuel-injection manifold, through the annular fuel-injection port and into the main combustor.

As the interface contacts the oxygen stream of the central oxygen tube, ignition occurs at the injector face and is sustained by the propelling hydrogen fuel. During the sustained combustion, the spark-plug tip remains cool and clean. Without a spark-plug port, the main combustor can be cooled efficiently.

Eighteen tests have proven this injector design; no ignition failures occurred in 8,000 seconds of operation with gaseous oxygen and hydrogen. The system can also be used with other propellants that are gaseous in the ignition phase.



After Ignition Occurs in the Fuel Injector, combustion is maintained in the cooled main combustor leaving the spark-plug tip in a cool, clean environment.

This work was done by Richard A. Pieron of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 73 on the TSP Request Card.*
MFS-29125

Rigid/Compliant Helicopter Rotor

The rotor structure ensures both effective aerodynamic support and efficient pitch changes.

Ames Research Center, Moffett Field, California

A conceptual helicopter rotor design includes blade-root structures that are rigid in flexure but compliant in torsion. The four blades are shells with rigid inner I-beam arms that are integrated with the rotor hub. Through each blade, a control arm extends from a pitch-control actuator in the hub (see figure). Elastomeric bearings allow the control arms to twist the blades and thus change the blade pitch without turning the I-beam arms. Centrifugal force is carried by a tension strap. Leading and lagging movements of the blades are restrained by dampers. Ducts inside the leading and trailing edges of the blade shells carry air for partial cyclic aerodynamic control of lift and pitch.

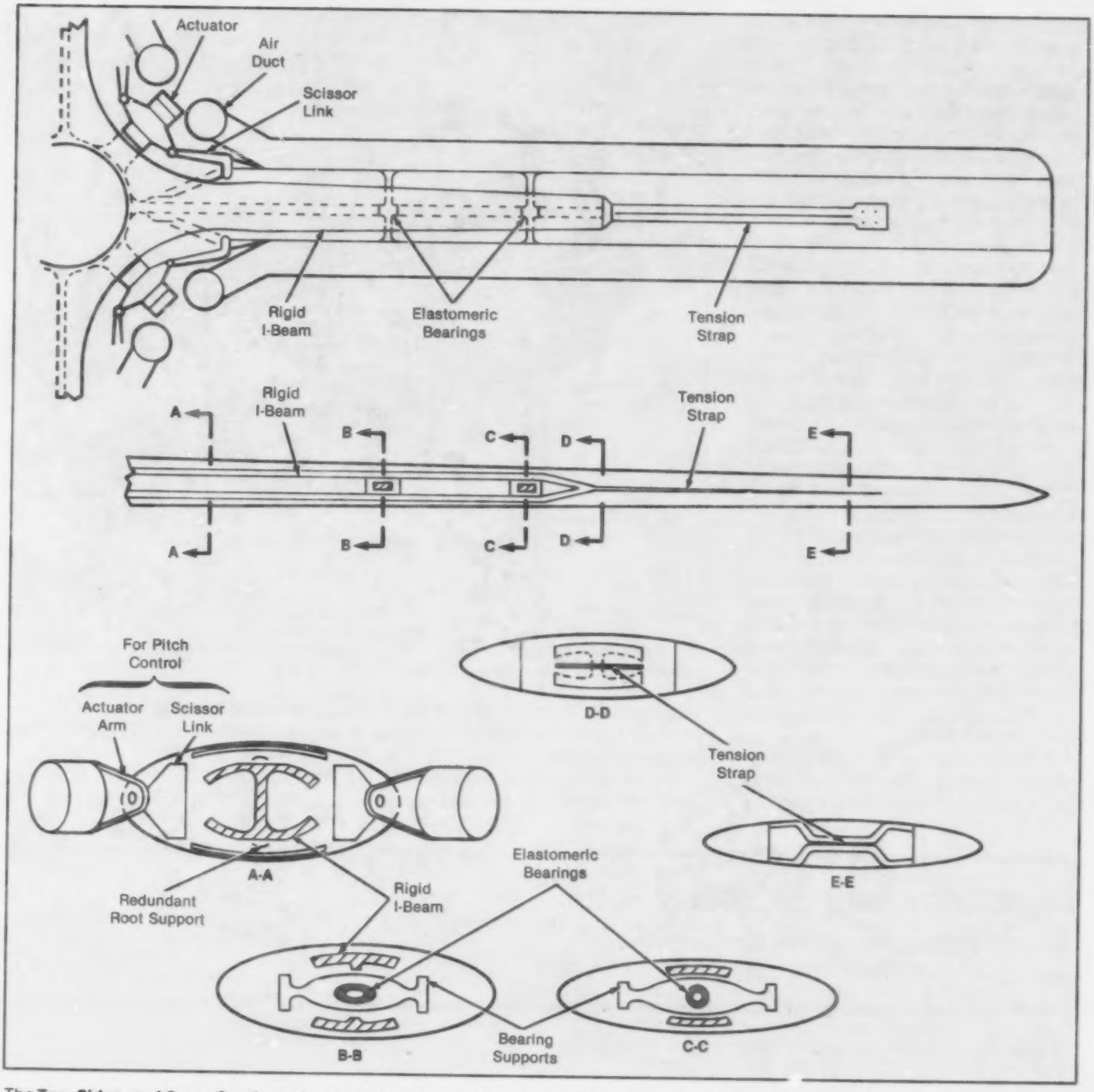
The pitch of the blades is varied collectively by synchronized rotation of the actuator arms on the hub at the blade roots, which apply torsion to the blades. The tension straps offer negligible restraint to torsion and thus allow the actuator arms to twist the blades freely. If an actuator arm should fail, a redundant arm at the root of the same blade provides continued control and support. The redundant arm and bearings are normally separated by a small gap but make contact when a failure occurs.

Because the control arms support the blades at their roots, root bearings are not needed. Neither are thrust bearings needed, because the tension straps resist the centrifugal force. Because the blades can be twisted without twisting their I-beam arms, control forces are reduced. Moreover, because root bearings are not used and more space is therefore available at the roots, the I-beams can be designed to resist loads more efficiently.

This work was done by P. Jeffery of United Technologies Corp. for **Ames Research Center.** *Further information may be found in NASA CR-166399 [N82-32341/NSP], "Rotosystems Research Aircraft Vertical Drag Test Report."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11518.



The **Top, Sides, and Cross Sections** show details of the torsionally compliant, flexurally rigid rotor. The structure permits more efficient pitch control with less weight. At the same time, it improves reliability through redundancy in supports and control mechanisms.

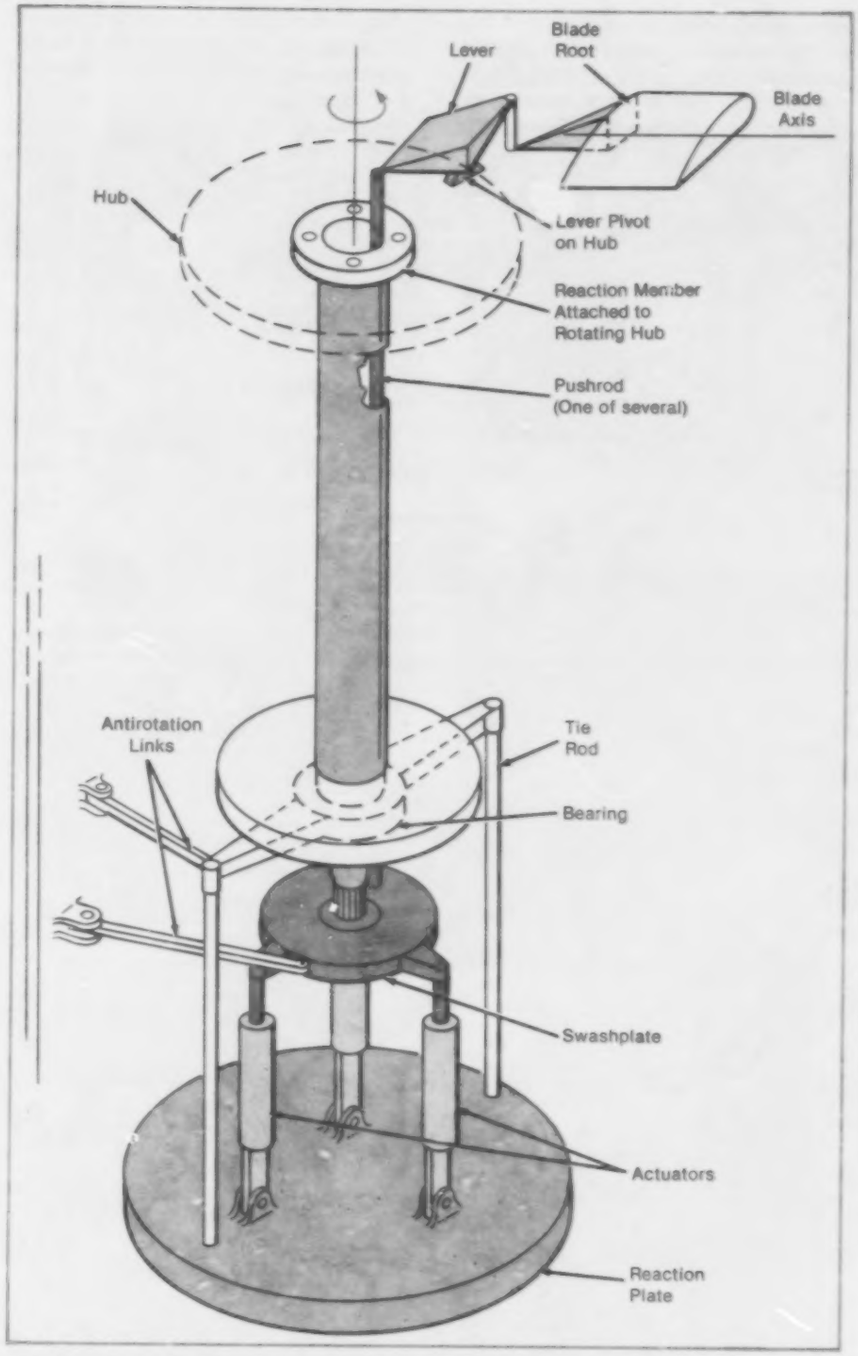
Helicopter Pitch-Control Mechanism Reduces Vibration

Large forces could be accommodated without increasing the weight of the helicopter structure.

Ames Research Center, Moffett Field, California

A proposed pitch-change mechanism for a helicopter rotor can prevent large control reaction forces from being applied to the gearbox or fuselage. The new mechanism would yield stiffer control and improve the accuracy of pitch changes under load. As a result, a heavy casting would not be needed for the gearbox, nor extra reinforcing members would be needed for the fuselage bulkheads, stringers, skin, and other parts. Distortion of the gearbox and consequent gear deflections would be avoided. In addition, the helicopter parts would be protected from the fatigue and early failures caused by the variable, cyclic nature of control forces.

The mechanism was developed for the "X-wing" aircraft, which employs a stiff rotor with four blades. Compressed air is blown



Reaction Forces for This Pitch Control Mechanism are provided in the rotor hub rather than in the fuselage or gearbox. Control forces are transmitted to the hub through the reaction plate and reaction member.

through slots in the leading and trailing edges of the blades for partial cyclic and collective pitch control. Additional mechanical collective pitch control is required for trimming the blades during hovering and high-speed fixed-wing flight. However, reaction loads for mechanical collective pitch control are quite high — about 60,000 lb (270,000 N). Without the new mechanism, the excess structural weight for resisting such loads would be prohibitive.

In the proposed mechanism, reaction forces are developed in the rotor hub. Long load paths to the gearbox and fuselage, as in previous helicopters, are eliminated. A reaction member is rigidly attached to the hub and rotates with it (see figure). At the lower end of the reaction member, a bearing forms a bridge to the fuselage through a stationary beam and an antirotation link. The beam is connected to a reaction plate through the rods.

Control actuators and a control swashplate, which can slide on the reaction member and tilt, are mounted on the reaction plate. An antirotation link secures the swashplate. Pushrods connect the swashplate through the reaction member to the rotor hub. At the hub, levers, links, and pitch arms connect the pushrods to the blades.

This work was done by H. Lemont of United Technologies Corp. for **Ames Research Center.** *Further information may be found in NASA CR-166399 [N82-32341/NSP], "Rotosystems Research Aircraft Vertical Drag Test Report."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11513

Controlled-Temperature Hot-Air Gun

Materials are tested before installation in wind tunnels.

Lyndon B. Johnson Space Center, Houston, Texas

Materials that may find applications in wind tunnels are first tested in the laboratory with the setup shown in the figure. Resembling an elaborate but carefully regulated hot-air gun, the setup is used to apply blasts of air at temperatures above 1,500 °F (815 °C) to the test specimens.

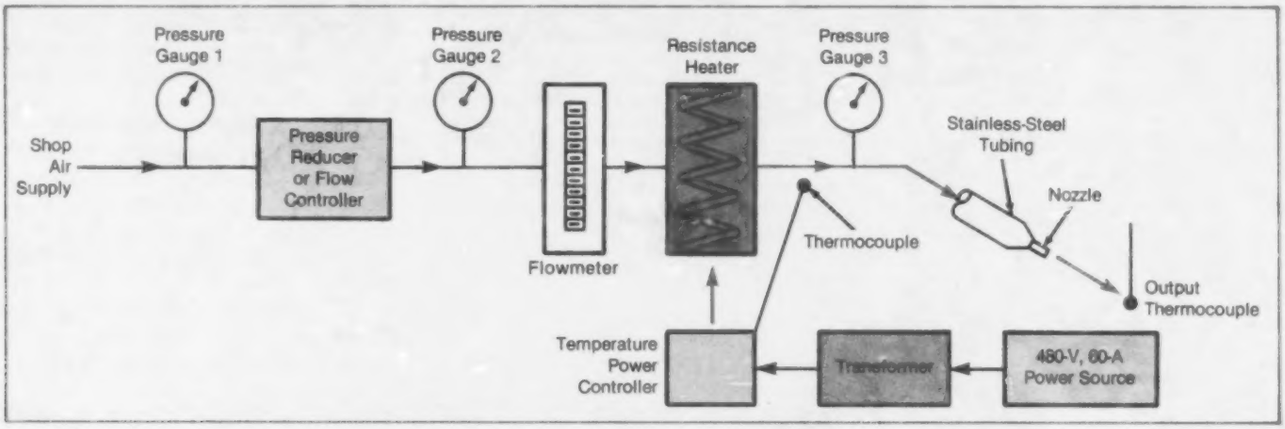
A typical test sequence is the following:

- The shop air supply is turned on at gauge 1.
- The heater power is turned on and adjusted to obtain approximately the desired temperature at a thermocouple near the nozzle.

- The pressure is adjusted at gauge 2 to "fine tune" the output temperature.
- Further fine adjustments of the pressures, temperatures, and flow are made until the conditions in the air blast just outside the nozzle are those at which a specimen is to be tested.

The specimen is mounted on a tripod-supported stand, the top of which can be slanted. The slant angle is adjusted for the required angle between the air blast and the specimen surface.

This work was done by Max C. Munoz of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 85 on the TSP Request Card.*
MSC-20693



The **Hot-Air Gun** differs from commercial units in that the flow rate and temperature are monitored and controlled. With a typical compressed-air-supply pressure of 25 to 38 psi (170 to 260 kPa), the flow rate and maximum temperature are 34 $stdft^3/min$ (0.96 $stdm^3/min$) and 1,090 °F (590 °C), respectively.

Adjustable Tooling for Bending Brake

Deep metal boxes and other parts are easily fabricated.

Lyndon B. Johnson Space Center, Houston, Texas

An adjustable tooling jig for a bending brake accommodates spacing blocks and either a standard male press-brake die or a bar die. By increasing the free space available for bending sheet-metal parts, the jig makes it easier to fabricate such items as deep metal boxes or brackets with right-angle bends.

As shown in Figure 1, the jig is interposed between the press brake and one of the press-brake dies — in this case, the male die. Spacer blocks are fabricated to the required dimensions as needed by cutting them from metal scraps.

To make deep metal boxes. the jig is used in the configuration of Figure 1 (spacer-block mode). A typical forming operation in this mode is shown at the top of Figure 2.

To fabricate smaller parts with multiple right-angle bends, the window-die mode is used. In this configuration, the press-brake die is removed from the bottom of the jig, and a round or square bar is clamped between the upper and lower 90° grooves. The bar then serves

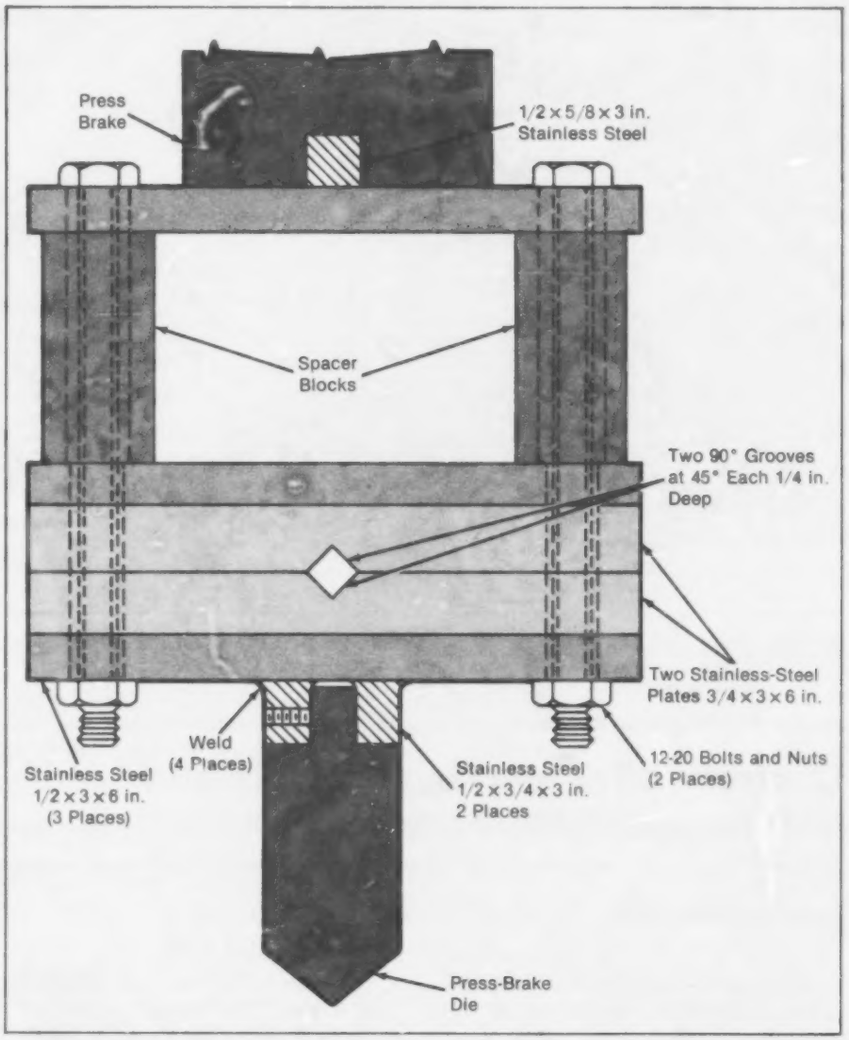

Press Brake
1/2 × 5/8 × 3 in. Stainless Steel
Spacer Blocks
Two 90° Grooves at 45° Each 1/4 in. Deep
Two Stainless-Steel Plates 3/4 × 3 × 6 in.
Weld (4 Places)
Stainless Steel 1/2 × 3 × 6 in. (3 Places)
Stainless Steel 1/2 × 3/4 × 3 in. 2 Places
12-20 Bolts and Nuts (2 Places)
Press-Brake Die

Figure 1. The **Adjustable Tooling Jig** holds spacer blocks, a press-brake die, a bar window die, or a combination of the three.

as the male bending die, cooperating with a female die consisting of a grooved block placed on the lower press-brake surface.

A forming operation in the window-die mode is shown in the lower half of Figure 2.

This work was done by James M. Ellis of **Johnson Space Center.** *No further documentation is available. MSC-20730*

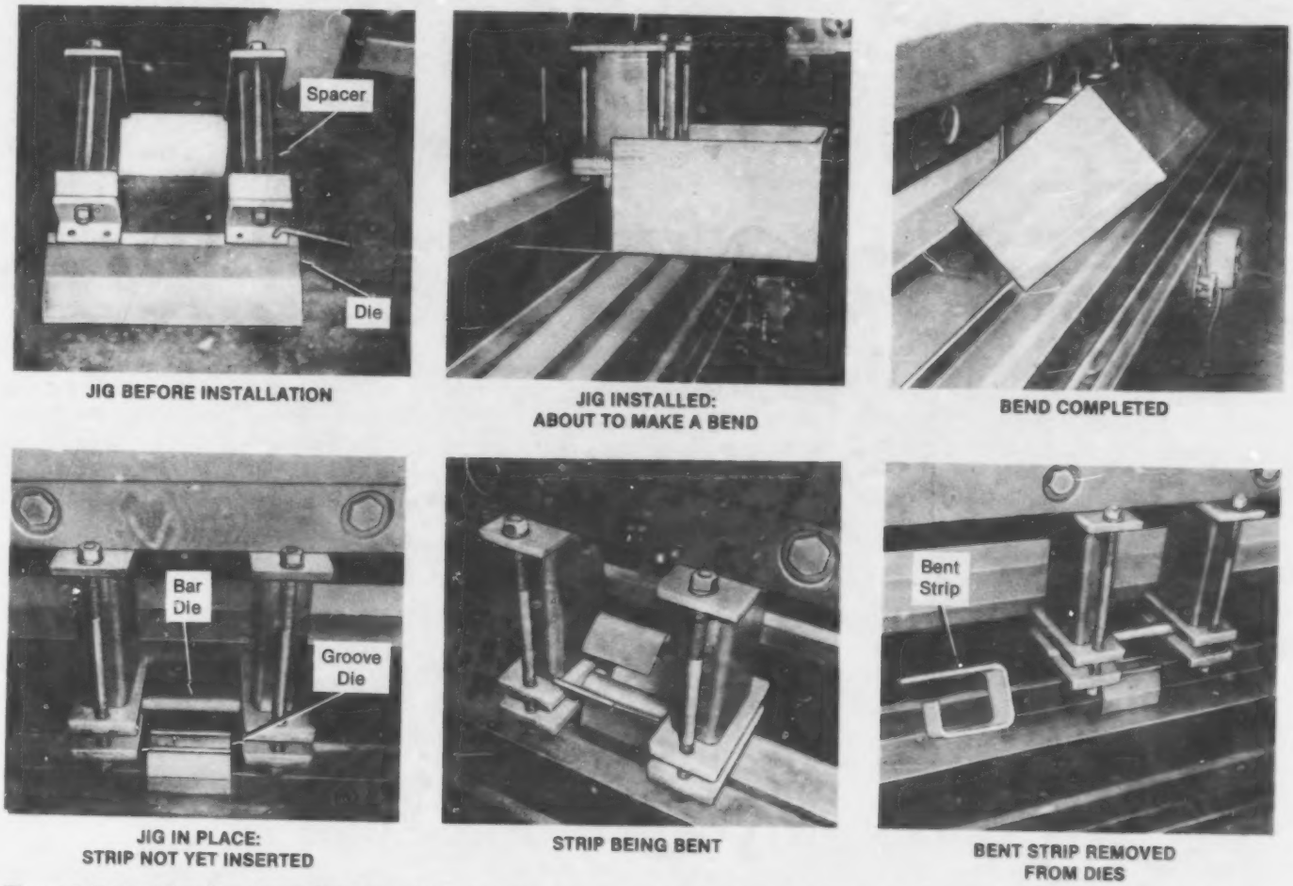


Figure 2. **Typical Bending Operations** include the bending of a cut metal sheet into a box (above) and the bending of a metal strip into a bracket with multiple inward 90° bends (below).

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Orbital-Transfer Vehicle With Aerodynamic Braking

The vehicle would include an airbrake for deceleration into a lower orbit.

A report describes a proposed vehicle for carrying payloads between low and high orbits around the Earth. The vehicle would use the thin, upper atmosphere for braking when returning to a low orbit. Since less propellant would be needed than would be required for full retrorocket braking, the vehicle could carry a larger payload and therefore reduce the cost of space transportation.

Unlike previously proposed aerobraking orbital transfer vehicles (AOTV's), it would be an integrated structure in which supports for the aerobrake, the rockets, the fuel tanks, and other subsystems are shared to obtain more efficient use of structural elements and therefore smaller mass.

The aerobrake surface would be a wide-angle cone of elliptical cross section, with a toroidal skirt and an apex blunted to an ellipsoid. It would be made of aluminum with a rigid thermal-protection layer. During braking, it would shield the rockets, tanks, and payload like an umbrella in the wind. The structure would be assembled in space and could be used many times to carry payloads in both directions between low Earth orbit and space stations. Once assembled, the vehicle would not return to the surface of the Earth, but would exchange payloads with the Space Shuttle in orbit.

The report covers such topics as aerodynamics, propulsion, structural mass, aerobrake heating, thermal protection, and vehicle performance. In a section on technology improvements, the report notes that certain advances would lead to improved design and performance. Engines with greater specific impulse, for example, would reduce the masses of the tank and propellant. The development of composite structural elements would reduce mass without decreasing strength and rigidity. The use of fabric or soft insulation would reduce mass while improving strength and heat resistance.

This work was done by Carl D. Scott, Kornel Nagy, Barney B. Roberts, Robert C. Ried, Kenneth Kroll, and Joe Gamble of **Johnson Space Center.** *To obtain a copy of the report, "Design Study of an Integrated AOTV Concept," Circle 77 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20921.

Algorithm for Calibrating Robot Arms

Robots can be made to less demanding specifications and yet be more accurate.

A software-based calibration method for robots increases the accuracy with which manipulators are positioned. The method, described in a published paper, can be used on any serial-link robot with any combination of revolute and primatic joints.

The method increases the accuracy of positioning the manipulator at any point in the workspace relative to a fixed coordinate system. Accurate absolute positioning capability is particularly useful for those tasks where the robot is issued a target location by external sensory devices, such as a vision system. With the new method, ultraprecise manufacturing and high-resolution measurements of robot components are unnecessary. The method therefore reduces the cost of robots in addition to increasing robot accuracy.

This method is based on a study of the geometric relationships among the robot joints and links, error parameters, and position-sensor measurements. Matrix/vector equations are derived to express the transformations between the robot-link and stationary reference frames.The resulting algorithm and computer program provide a means with which the geometric link parameters are estimated. The singularities which arise from using the Denavit-Hartenberg parameters for parallel or near parallel consecutive joint axes are avoided by definition of a new set of link parameters.

The simulation part of the program sets up a mathematical model of the robot to be calibrated and tests the performance of the calibration method. The inputs to the simulation part include the link-parameter biases, joint-state variable-measurement errors, and end-point measurement-error statistics. The program then causes the computation of the nominal and actual end-point positions for several joint-state configurations. The eventual result of the simulation is a comparison of how well the biases are estimated. The simulation part of the program can also be used to interpret the results of a calibration.

The calibration part is similar to the simulation part. The manipulator is moved to a designated point, and the state variables and end-point position are measured. The computer calculates new bias values from these measurements. The program causes this procedure to be repeated until there is no further improvement in the accuracy of the estimates of the end-point positions.

After deriving the calibration equations and algorithm, the paper describes the software and gives examples of its use with two types of robots: the Puma 600 and the Stanford Arm. The numerical results of simulations on these robots show that the calibration technique can improve the absolute positioning accuracy of serial-link manipulators using only end-point measurements.

This work was done by Samad A. Hayati of Caltech and Majdedin Mirmirani of California State University, Los Angeles for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the paper, "A General Software for Robot Geometry Calibration," Circle 53 on the TSP Request Card.*
NPO-16569

Overcoming Robot-Arm Joint Singularities

Kinematic equations allow an arm to pass smoothly through a singular region.

A report discusses mathematical singularities in the equations of robot-arm control. An operator commands a robot arm to move in a direction relative to its own axis system by specifying a velocity in that direction. This velocity command is then resolved into individual-joint rotational velocities in the robot arm to effect the motion. However, the usual resolved-rate equations become singular when the robot arm is straightened.

One solution is simply to avoid the singular position of the robot arm; but in using resolved-rate equations, the operator's commands to move the arm as desired may cause the arm to pass inadvertently through a singularity. Erratic motion may result until the arm moves sufficiently far from the singularity. To overcome this elbow-joint singularity, a new set of kinematic rate equations has been developed to allow continued translational control of the robot hand, even though the robot arm is fully, or almost fully, extended.

These kinematic equations, instead of the regular resolved-rate equations, can be used to translate the robot hand in the neighborhood of the singularity. The kinematic equations give the operator the option to bend the robot arm at the elbow in either the up or down position. The operator simply extends the arm and backs it up again to reverse automatically the direction of the elbow bend (a difficult maneuver for the usual resolved-rate equations).

The equations were applied to move a graphically-simulated robot arm, and the desired motions were successfully obtained. Finally, two integration methods (Euler and Adams-Bashforth second-order predictor) were compared for three integration-step sizes (1/16-, 1/32-, and 1/64-s) with little or no differences seen in either set of tests. It therefore appears that a user constrained in the area of computer power could take advantage of the simpler Euler-integration scheme with a step size of 1/16 s, but this decision would depend on the specific situation.

This work was done by L. Keith Barker and Jacob A. Houck of **Langley Research Center** *and Susan W. Carzoo of Sperry Corp. Further information may be found in NASA TP-2376 [N85-15446/NSP], "Translational Control of a Graphically Simulated Robot Arm by Kinematic Rate Equations That Overcome Elbow Joint Singularity" [$8.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
LAR-13415

Theory and Tests of Two-Phase Turbines

New turbines open the possibility of new types of power cycles.

A report describes the theoretical analysis and experimental testing of two-phase impulse turbines. Such turbines open the possibility of new types of power cycles operating with extremely wet mixtures of steam and water, organic fluids, or immiscible liquids and gases. Possible applications are geothermal power, waste-heat recovery, refrigerant expansion, solar conversion, transportation, and engine-bottoming cycles. Potential advantages over conventional vapor cycles in these applications are the more effective use of the energy in such hot liquids as geothermal fluids, better matching to sensible-heat sources, lower shaft speeds, and the flexibility of operating without the restriction of dry-vapor expansion.

The two-phase turbines were tested with water-and-nitrogen mixtures and with Refrigerant 22 ($CHClF_2$). Nozzle efficiencies were 0.78 (measured) and 0.72 (theoretical) for water-and-nitrogen mixtures at a water/nitrogen mixture ratio of 68 by mass and were 0.89 (measured) and 0.84 (theoretical) for Refrigerant 22 expanding from 0.02 quality to 0.28 quality, where "quality" is defined as the ratio of vapor mass to total mass in a local fluid sample. The theoretical velocities are lower than those measured, probably because of an overestimation of drop size.

Blade efficiencies (shaft power before windage and bearing loss divided by nozzle jetpower) were 0.63 (measured) and 0.71 (theoretical) for water-and-nitrogen mixtures and 0.62 (measured) and 0.63 (theoretical) for Refrigerant 22 with a single-stage turbine and were 0.70 (measured) and 0.85 (theoretical) for water-and-nitrogen mixtures with a two-stage turbine. The measured rotor efficiencies are 10 to 15 percent below the calculated values because of sideways spreading of the liquid on the blades and retention of a liquid film by the blades. It is not known whether these losses can be reduced or whether they are fundamental limitations.

Although the efficiency of single-stage two-phase turbines will be only about 50 percent, this is sufficient for replacing the throttling steps in geothermal plants, refrigeration systems, and other systems that use irreversible flashing processes. However, it is problematic whether the value of the added energy output will offset the cost of the turbine and associated equipment. To compete with vapor turbines, a two-phase turbine must have an efficiency of more than 65 percent — about the upper limit of efficiency for two-phase turbines, and probably attainable only with organic working fluids.

In sum, two-phase turbines appear promising in organic-fluid waste-heat or geothermal binary cycles where there is a significant thermodynamic advantage in using saturated-liquid expansion and where the flow conditions are conducive to the best two-phase turbine efficiency. Two-phase turbines using steam and water expanding to the low pressures required in most applications, such as geothermal, may be ruled out by low efficiency and possibly erosion.

This work was done by David G. Elliott of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-168834 [DE82013037], "Theory and Tests of Two-Phase Turbines" [$14.50]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*
NPO-16039

Crash Tests of Protective Airplane Floors

Energy-absorbing floors reduce structural buckling and the impact forces on occupants.

A 56-page report discusses crash tests of energy-absorbing aircraft floors. It describes the test facility and procedures; the airplanes, structural modifications, and seats; the crash dynamics; the floor and seat behavior; and the responses of anthropometric dummies seated in the airplanes. The report also presents plots of the accelerations, photographs and diagrams of the test facility, and photographs and drawings of the airplanes before, during, and after testing.

Three six-place, low-wing, twin-engine airplanes were crashed under controlled free-flight conditions. One airplane had a conventional floor. Each of the other two airplanes was modified to incorporate one of two load-limiting (energy-absorbing) subfloors.

The modified portion of the subfloor structure extended from the main wing spar to aft of the rear cabin door. The upper floor panel was not changed, but the keel beams, bulkheads, stringers, and lower contour skin were removed. These were replaced, in one case, by a corrugated-beam, notched-corner subfloor structure, in the other, by a flat-beam, notched-corner subfloor structure.

All airplanes were allowed to strike a concrete surface at a speed of about 37 meters per second and at an angle of 15°. In each case, the airplane struck the ground squarely on its bottom (at a pitch angle of 0°) with the landing gear retracted.

The lowest floor accelerations and the least seat crushing — as well as the greatest subfloor crushing — occurred in the modified airplanes. The most effective of the two energy-absorbing subfloors was the corrugated-beam, notched-corner structure. This subfloor reduced the peak deceleration at the seats to the range of 25 to 30 times the gravity, as compared with a range of 40 to 55 times the gravity for the unmodified airplane. The structural crushing of the energy-absorbing subfloors minimized the upward heave of the cabin floor.

Crash pulses — the normal transverse and longitudinal acceleration histories — were recorded on five seated dummies and at various points on the structure. The accelerations on the dummies generally reflected the same trends as the accelerations on the structures. Lower accelerations occurred on the modified-subfloor airplanes.

This work was done by Huey D. Carden of **Langley Research Center.** *Further information may be found in NASA Technical Paper 2380 [N85-13267/NSP], "Full-Scale Crash Test Evaluation of Two Load-Limiting Subfloors for General Aviation Airframes."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LAR-13414

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Books & Reports

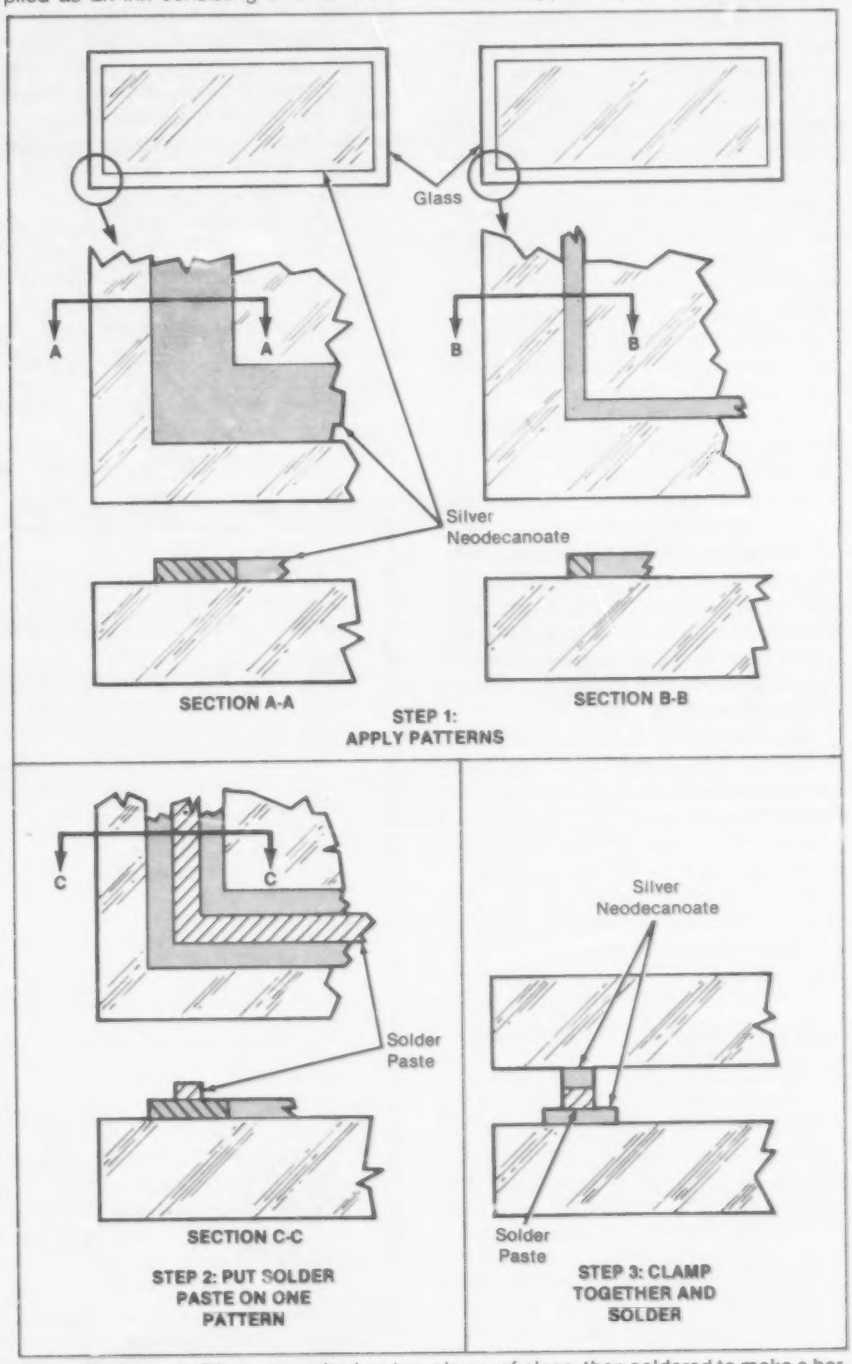
147 Theoretical Foundation for Weld Modeling

Thermally-Activated Metal-to-Glass Bonding

Hermetic seals are formed easily by use of a metallo-organic film.

NASA's Jet Propulsion Laboratory, Pasadena, California

A metallo-organic film is thermally bonded to glass and soldered or welded to form a hermetic seal. The film is applied as an ink consisting of silver neodecanoate in xylene. The relative amounts of the ingredients are selected to obtain the desired viscosity. The material can be applied by printing or even by



A **Metallo-Organic Film** is deposited on two pieces of glass, then soldered to make a hermetic seal.

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scribing with a pen.

The figure illustrates a representative procedure for making a hermetic seal between two flat pieces of glass. First, the ink is deposited on the two pieces in matching patterns. The pattern on the lower piece has slightly wider lines. The glass pieces then are heated in air to 260°C to evaporate the xylene and decompose the silver neodecanoate, leaving adherent patterns on the glass.

Solder paste is deposited on the wider lines and dried normally. The upper glass is placed over the lower glass with its metal pattern resting on the solder paste. The pieces are clamped together and soldered, using the standard thermal cycle specified for the solder.

In semiconductor packaging, the customary line width for hermetic seals is about 1 mm. If the seal is to encapsulate electronic circuitry that must not be overheated, the heat for decomposition and soldering can be supplied by a laser to confine the high temperature to the seal region. This sealing technique should be useful in making solar-cell modules, microelectronic packages, and other hermetic silicon devices.

This work was done by Brian D. Gallagher of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 58 on the TSP Request Card.*

Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 29]. Refer to NPO-16423.

Electrochemical Process Makes Fine Needles

The improved process is less tedious than manual dipping and can be left unattended.

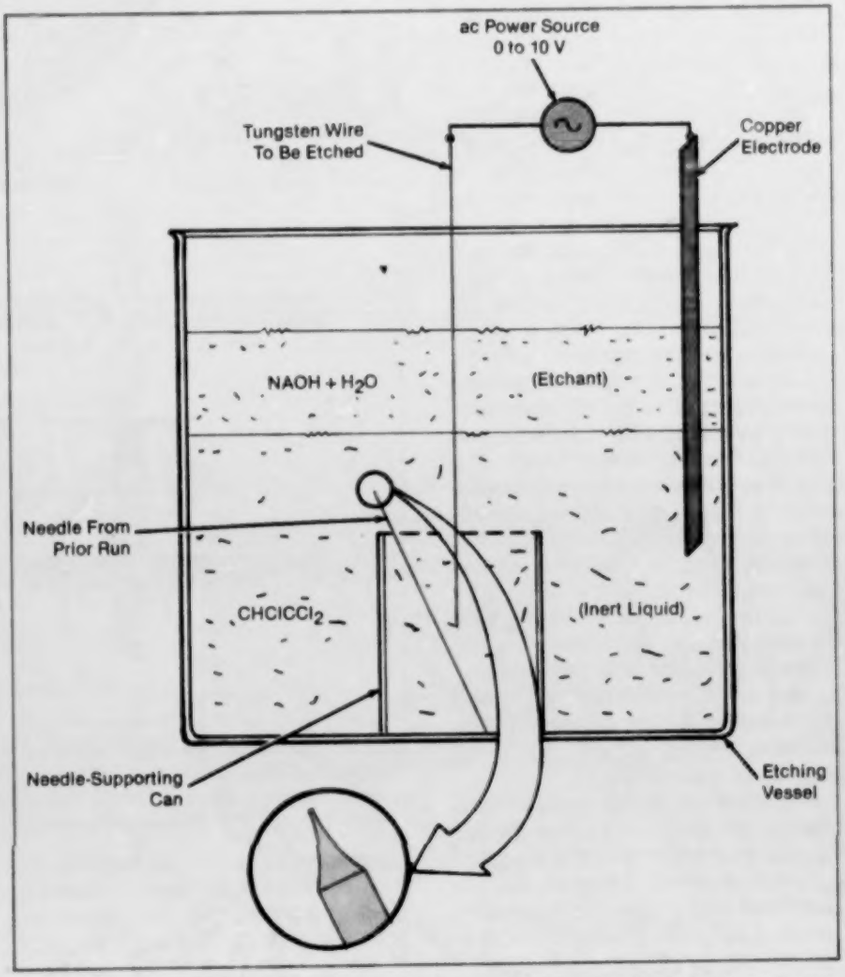
NASA's Jet Propulsion Laboratory, Pasadena, California

An electrochemical process makes fine tungsten needles for use as microscopic probes or field-emission cathodes. Until now, fine needles were produced from tungsten wire by tedious manual dipping in an etching solution, with careful minute-by-minute inspection to determine when the etching should be stopped. The improved process does not require close monitoring and can be left unattended for an indefinite time.

The process uses sodium hydroxide in water as a caustic etching liquid and trichloroethylene, a denser, immiscible, inert fluid underneath the etchant. As shown in the figure, the tungsten wire is suspended from above the etching vessel; the lower end of the wire is in the trichloroethylene. A copper electrode is placed elsewhere in the vessel. An alternating voltage — usually 6 to 7 V — is applied between the wire and the electrode.

Wires of 0.010- to 0.015-in. (0.25- to 0.38-mm) diameter are etched in 5 to 10 min. The portion of the wire in the etchant gradually thins to a filament, then breaks into two segments having pointed ends. The lower segment sinks into the trichloroethylene and is not etched any further. A can or other support may be placed at the bottom of the vessel to catch the sinking needle and protect the tip.

The newly formed needle can be lifted out with forceps or left at the bottom of the vessel while new segments of wire are etched. If the apparatus is left unattended as a needle is formed, no harm is done: The needle falls to the bottom as usual, and the upper wire segment in the caustic solution eventually dissolves completely, interrupting the electrical current. In principle, the process can accommodate dozens of wires connected electrically in parallel, so that many needles can be formed in one batch.



The Etching Vessel is filled with a dense, inert lower liquid covered by a less-dense, caustic etching solution. The newly formed needle breaks off the upper part of the wire in the etchant and falls into the can in the inert liquid below.

This work was done by John L. Watkins of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 9 on the TSP Request Card.*
NPO-16311

Filters for Submillimeter Electromagnetic Waves

Stacked square wires are plated, fused, and etched to form arrays of holes.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new manufacturing process is expected to produce filters that are strong, yet have the small, precise dimensions and smooth surface finish essential for dichroic filtering at submillimeter wavelengths. Many filters, each one essentially a wafer containing a fine metal grid (see figure), can be made at the same time.

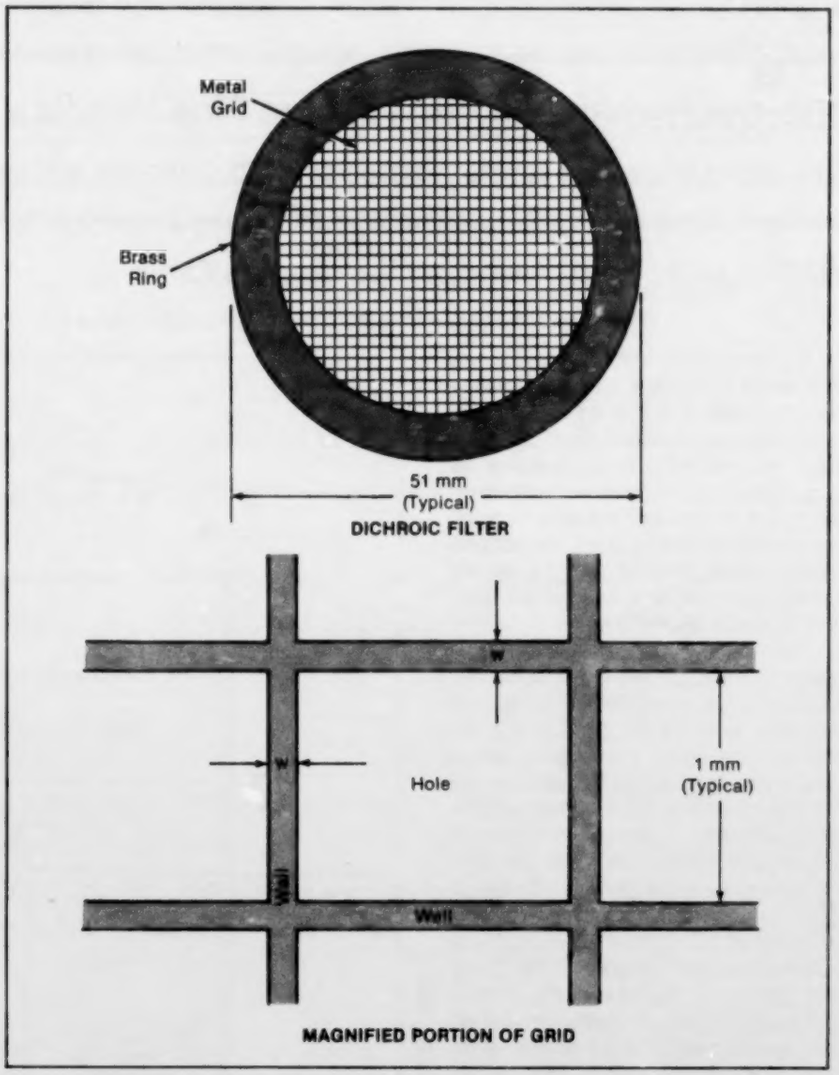
The starting material is the wires. They should be square in cross section and straight with sharp corners and smooth sides. The square-cross-section wires can be made by drawing round wires through a die. A die composed of four silicon carbide side plates held in a clamping block would ensure the sharp edges needed for accurate filtering.

The wires are cut to lengths of about 24 inches (61 centimeters), suitable for the depth of the available plating tank. The wires are suspended in an electroless nickel-plating bath, and a coating of nickel is formed on them. (Electroless plating is used because it gives a fairly even nickel coat, wheras electroplating builds up undesired thickness along the wire edges.) Optionally, the wires may then be coated with a thin layer of pure tin to facilitate subsequent soldering. The combined thickness of nickel and tin should be less than one-twentieth the thickness of a wire. The nickel-plated, tinned wires are cut to a length of 2 inches (5 centimeters). Two semicylindrical bundles of the cut wires are stacked in a semicylindrical aluminum trough and clamped in the trough by a flat plate on the open diameter so that the wires are oriented uniformly with flat surfaces parallel to the plate. The trough and strips are placed in a furnace and heated to melt the tin. (The tin does not adhere to the aluminum.)

In a faster and easier version of the process, the wires are packed directly into brass semicylinders. With the semicylinders clamped together, the assembly is fused or subjected to capillary sweating with G35n/37Pb solder.

After cooling, the two bundles in their solid tin matrix are clamped between tinned brass half cylinders, having an outside diameter equal to the required outside diameter of the finished filter. They are placed in the furnace and fused together. The cylinder thus formed is sawed into wafers, then lapped and polished to the thickness required for the cutoff frequency. The wire cores are electrolytically etched from the wafers, leaving a grid of nickel in the solder or tin matrix. A subsequent thin gold plate of the etched wafer will assure good electrical performance.

The wire may be aluminum, copper, brass, silver, or other material. The etching electrolyte contains ions of the wire metal only. With the wire cores connected as anodes, the cores are etched away. With the proper choice of etching conditions, the nickel plate and solder should not be attacked significantly.



A Grid of Nickel and Tin is held in a brass ring. The wall thickness, the thickness of the filter (hole depth), and the lateral hole dimensions all depend upon the operating frequency and filter characteristics. The dimensions shown are for a filter with a center wavelength of 1.4 millimeters. The thickness of the filter is 1.2 millimeters.

This work was done by C. Martin Berdahl of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 57 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office - JPL [see page 29]. Refer to NPO-16498.

Weld Repair of Thin Aluminum Sheet

A shield and heat sinks protect the area adjacent to the weld.

Lyndon B. Johnson Space Center, Houston, Texas

Weld repairing of thin aluminum sheets is now possible, using a niobium shield and copper heat sinks. In the past, weld repairing of thin aluminum sheets has not been possible, because of high-frequency-induced surface cracks and heat checks. The refractory niobium shield protects the aluminum adjacent to the hole, while the copper heat sinks help conduct heat away from the repair site. This technique limits the tungsten/inert-gas (TIG) welding bombardment zone to the melt area, leaving surrounding areas around the weld unaffected.

The figures illustrate the application of the new technique to the face sheet of a cold-plate assembly. Before welding, the fracture, dent, or puncture in the face sheet is machined away, leaving a smooth hole so that the rough edges and cracks are removed. After cleaning, the face-sheet edge at the hole is then depressed into the core cavity. As shown in Figure 1, the niobium heat shield and copper tooling are clamped over the area to be repaired.

As welding is initiated, the high-frequency-induced surface cracks are taken into the weld melt. The undercut (or countersink) on the back side of the niobium heat shield allows the molten weld to flow outward and away from the bombardment zone. Thus, the weld and its peripheral areas are free of high-frequency-induced surface cracks and heat checks. Figure 2 shows the resulting weld configuration.

This technique has been used successfully to repair aluminum cold plates on the Space Shuttle, resulting in a substantial cost saving and reducing delays. It also will have commercial applications, especially in sealing fractures, dents, and holes in thin aluminum face sheets or clad brazing sheet in cold plates, heat exchangers, coolers, and Solar panels. While particularly suited to thin aluminum sheet, this process also can be used in thicker aluminum material to prevent surface damage near the weld area.

This work was done by Charles S. Beuyukian and Mike J. Mitchell of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20902

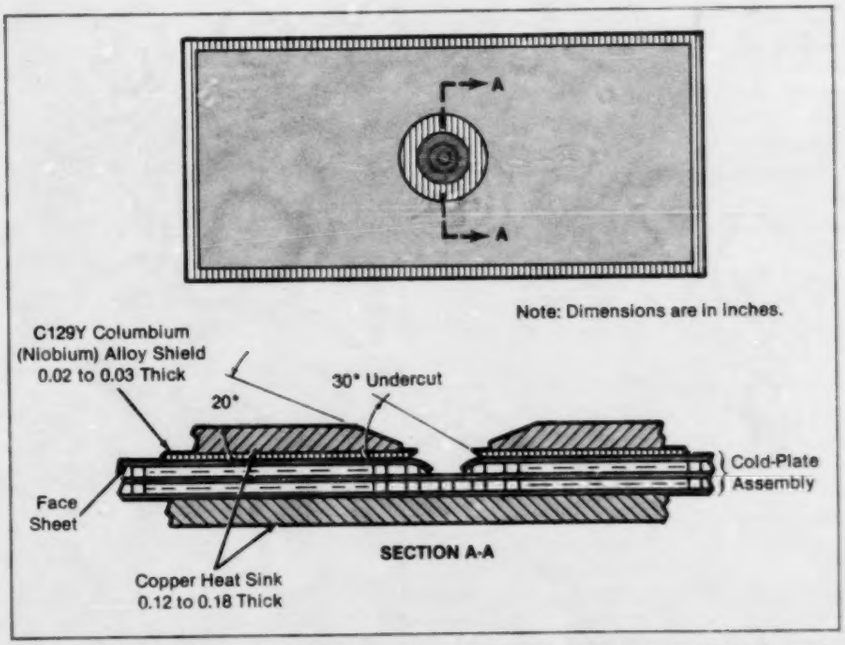


Figure 1. **Before Welding,** the edge of the hole in the face sheet is depressed into the cavity, and the shield and heat sink are clamped in place.

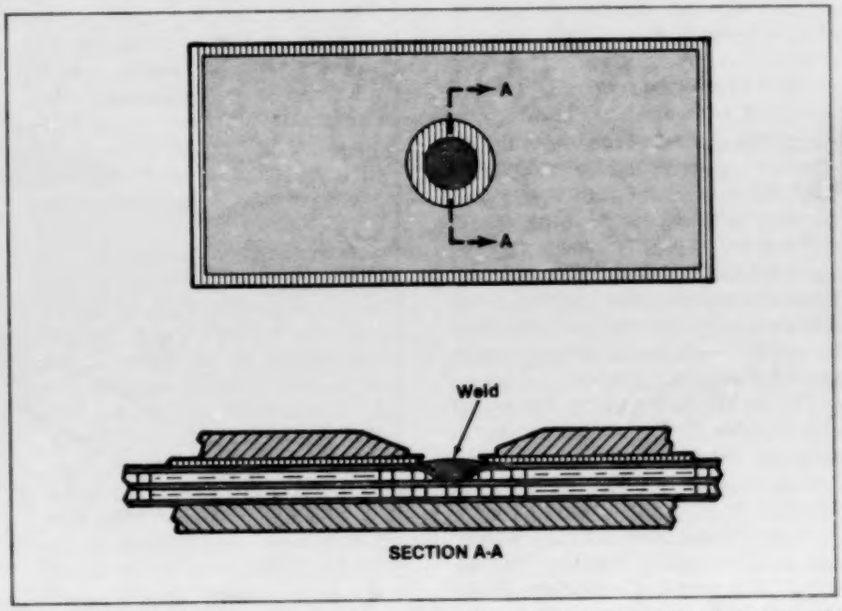


Figure 2. The **Weld Melt** flows beyond the edge of the undercut, where heat checking and cracking do not take place. Thus, the entire weld is free of cracks and heat checks.

Repairing Hard-to-Reach Cracks in Heat-Exchanger Tubes

Inaccessible leaks are repaired from accessible side of the tube.

Marshall Space Flight Center, Alabama

Tubes springing leaks on inaccessible surfaces can be repaired by a "fish-mouth" insert and two closeout patches. This method was developed for repairing leaks in the nozzle coolant tubes of the Space Shuttle main engine. Such a leak can occur on the side of a tube that touches the cold wall. Cutting through the wall to reach the cracked part of the tube is not feasible, but with the new method, the crack can be reached from the accessible opposite side. The method can also be used on other types of tubular heat exchangers.

A portion of the tube on the side opposite the crack is cut and removed (see figure). The opening should extend around one-half the circumference of the tube so that the insert can be slipped over the crack. The insert has an outside diameter equal to the inside diameter of the cracked tube. The insert is slightly shorter than the opening, and its slanted ends face the hot side, resembling a fish's mouth. These slanted ends are easily accessible for brazing or welding.

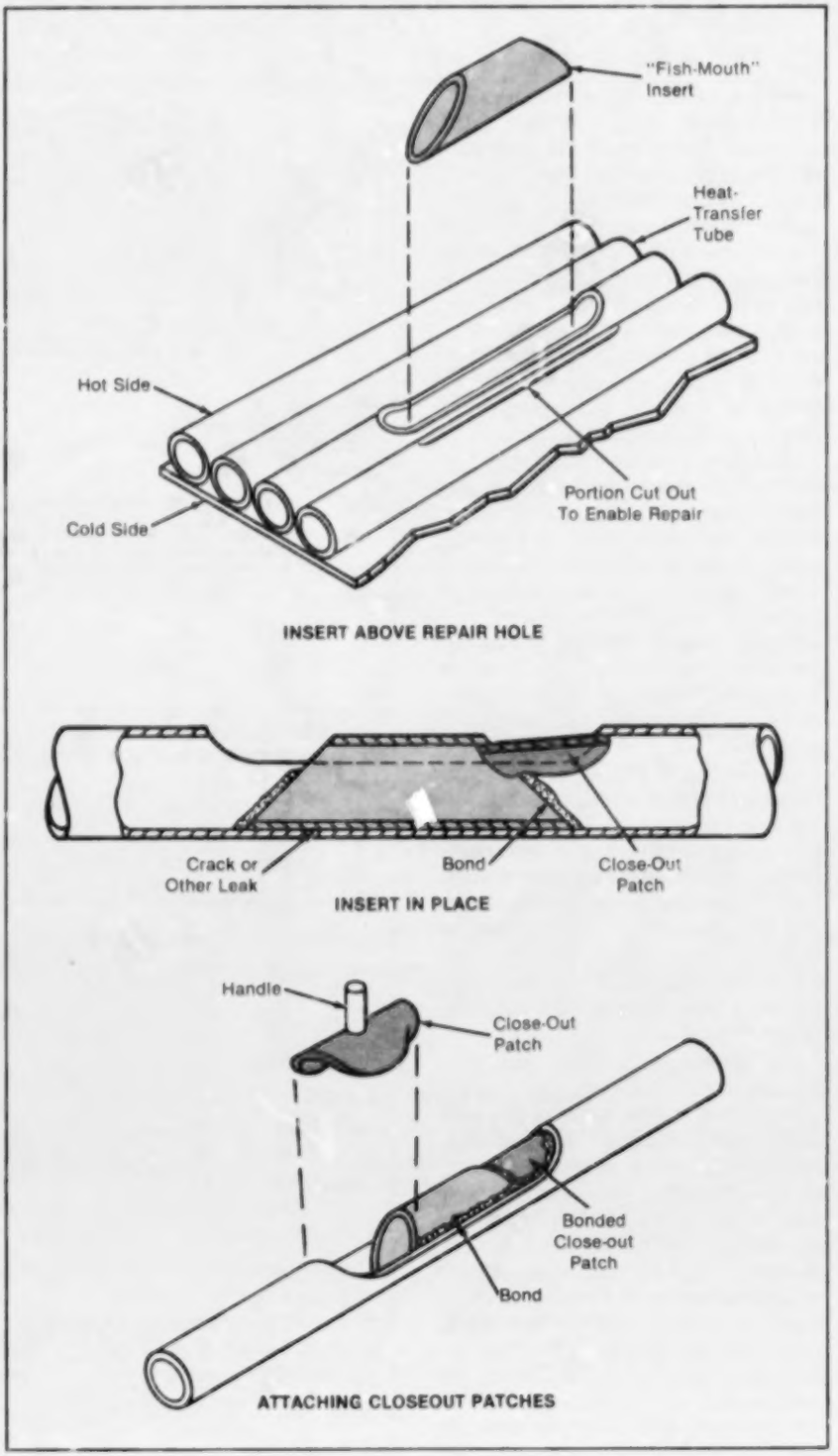
The insert is brazed or welded around its entire perimeter adjoining the cracked tube by tungsten/inert-gas apparatus. This seals off the crack. Longitudinal bonding of the insert to the tube wall further secures the insert and isolates the cracks.

After the insert is secured, two closeout patches are positioned over what remains of the opening. The patches, which are cut to match the edge contours of the tube opening and the insert ends, are welded to the assembly. Rod-shaped handles on the patches allow the welding-machine operator to grasp and manipulate them; the handles are cut off after the patches are secured.

The insert should be long enough to cover the cracked area. When adjacent tubes are repaired, the repaired tubes may have to be alternated with short ones so that the welding can be staggered to prevent side-by-side welds.

The insert not only seals cracks but also strengthens the tube structurally. It does not interfere with the flow of the heat-exchange medium and does not significantly degrade the heat transfer.

This work was done by R. C. Mills, Sr., and J. Duesberg of Rockwell International Corp. for **Marshall Space Flight Center.** *For further information, Circle 5 on the TSP Request Card.*
MFS-29128



A **Fish-Mouth Insert** is placed in a cut in a leaky heat-exchanger tube. The insert is welded or brazed to the tube, and the remaining open area of the cut is patched.

Depositing Diamondlike Carbon Films

Radio-frequency, plasma, and ion-beam techniques are used.

Lewis Research Center, Cleveland, Ohio

A new process has been demonstrated to make thin films (usually thousands of angstroms to a few microns thick) that have the properties of diamonds. These diamondlike properties include high scratch resistance, high electrical resistivity, high thermal conductivity, insolubility in concentrated H_2SO_4/HNO_3, and optical properties that include high transmittance at visible wavelengths.

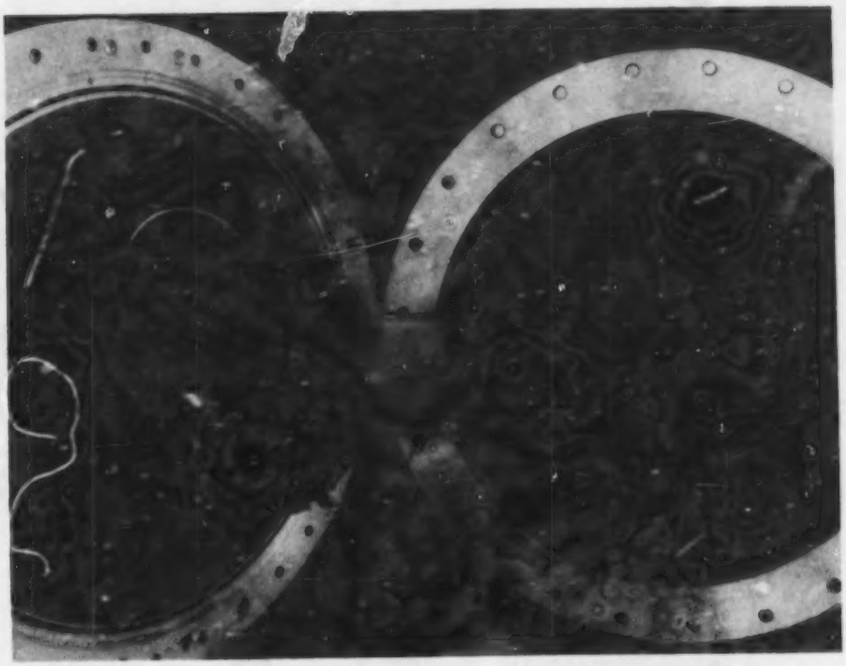
There have been many publications reporting efforts to produce carbon thin films with diamondlike properties. Various plasma and ion-beam techniques have been employed to generate the films. The films can be made by radio-frequency plasma decomposition of a hydrocarbon gas or other alkanes, by low-energy carbon-ion-beam deposition, or by ion plating and a dual ion technique using a carbon target.

Disadvantages of this prior art include the following:

- The quality of the films produced is such that the films appear to have a low electrical conductivity (1 to 10 Ω-cm), greater optical absorption (10^5 cm^{-1}), less resistance to chemical attack ($3H_2SO_4/1HNO_3$), and the films are softer and less dense.
- In some of the other techniques used to produce diamondlike films, the size of the substrate to be coated is limited. Also, the deposition rates are not as high.
- Another disadvantage is that because of the inability to control enough independent parameters, the films produced are stressed.

This unique process was developed to achieve films of superior quality; i.e., thin films that have the properties of diamonds. These thin films can be achieved by the following four processing steps:

1. Two ion sources, shown in the configuration in the figure, were used to generate the films.
2. The substrate (quartz, silicon, metals) is first exposed to an argon ion beam to clean absorbed gases and contaminants from its surface at energy levels between 500 and 1,000 eV and current densities of 0.5 to 2 mA/cm^2.
3. A 30-cm hollow-cathode ion source with its optics masked to 10 cm (as in the figure) is then used to deposit diamondlike films directly on a substrate. Argon gas is used in a hollow cathode to establish a discharge, and then CH_4 (methane) or other hydrocarbons are introduced into the discharge chamber as the main flow. The ideal ratio of CH_4 molecules to Ar atoms necessary to generate the films is 28 percent with energy levels between 80 and 150 eV. Ideal energy levels for generation of the films are 100 eV. With this energy level, it is necessary to have an accelerator voltage of −600 V to extract a beam.
4. To initiate a film, it is absolutely necessary for the current density to be low during initial deposition at the substrate (a typical value is one-half or less of the current density during full deposition) for periods of time varying from 3 to 30 min, depending on the substrate material. After this initial low-current condition, the 30-cm hollow-cathode ion source is set at the full-power current conditions, and then the 8-cm ion source using Ar gas at 200 to 500 eV is turned on with a current density at the substrate of 25 $\mu A/cm^2$. This addition of energy to the system increases mobility of the condensing atoms and also serves to remove lesser bound atoms. Typical deposited rates at these conditions are 70 to 80 Å/min. Liquid nitrogen was used in cold traps of the diffusion pumps and the cryoliner of the vacuum system during the deposition process.



This **Dual-Beam Ion Source** deposits films with properties like those of diamonds.

The advantages of this new process over others are that the films produced, though amorphous, are clear, extremely hard, chemically inert, of high resistivity, and have an index of refraction of 3.2 — properties that are similar to those of single-crystal diamonds. These films have possible uses in microelectronic applications, high-energy-laser and plastic windows, corrosion protection for metals, and other applications where the desired properties of the film can be shaped during the film-formation process.

This work was done by Michael J. Mirtich, James S. Sovey, and Bruce A. Banks of **Lewis Research Center.** *Further information may be found in NASA TM-83743 [N84-31512/NSP], "Dual Ion Beam Deposition of Carbon Films with Diamond Like Properties" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

This invention has been patented by NASA [U.S. Patent No. 4,490,229]. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 29]. Refer to LEW-14080.

Masking Technique for Ion-Beam Sputter Etching

Integrated-circuit surface structures have high aspect ratios.

Lewis Research Center, Cleveland, Ohio

An improved process for the fabrication of integrated circuits has been developed. Previous organic resists, metal, and metal-oxide masks limited the aspect ratio of surface structures, because the sputter mask has a finite sputter-etch rate. As the mask material etches away, the walls of the etched substrate become sloped or faceted rather than having ideal vertical walls.

Utilizing a technique that allows for the codeposition of carbon, the sputter mask can be made to have no net loss or even a slight gain in thickness with time. This allows very-high-aspect-ratio surface features to be ion-beam sputtered without concern for sputter-mask life. The sputter mask is replenished in a manner that allows a very thin sputter mask to be used. The ability to use thin masks that do not become thinner or narrower allows high-resolution sputter etching and straight walled features to be produced. Use of a carbon film for a sputter mask allows high rates of sputter etching because the sputter mask would not be heat-sensitive and a high ion-beam power density could be used.

This technique utilizes simultaneous ion-beam sputter etching and carbon sputter deposition in conjunction with a carbon sputter mask or an organic mask that can be decomposed (thermally or by ion-bombardment scission fragmentation) to produce a carbon-rich sputter-mask surface. This carbon surface can be extremely thin (a few hundred to a few thousand angstroms). The mask along with the unmasked portion of the substrate are bombarded typically with 200 to 3,000-eV inert-gas ions while simultaneous carbon deposition is occurring. The arrival of sputter- or vapor-deposited carbon can easily be adjusted to allow the sputter mask to have a nearly zero or even slightly positive increase in thickness with time, while at the same time the unmasked portion of the substrate has a high net sputter-etch rate. The reason for this disparity of etch rates is the large difference in sputter yield between carbon and all other materials.

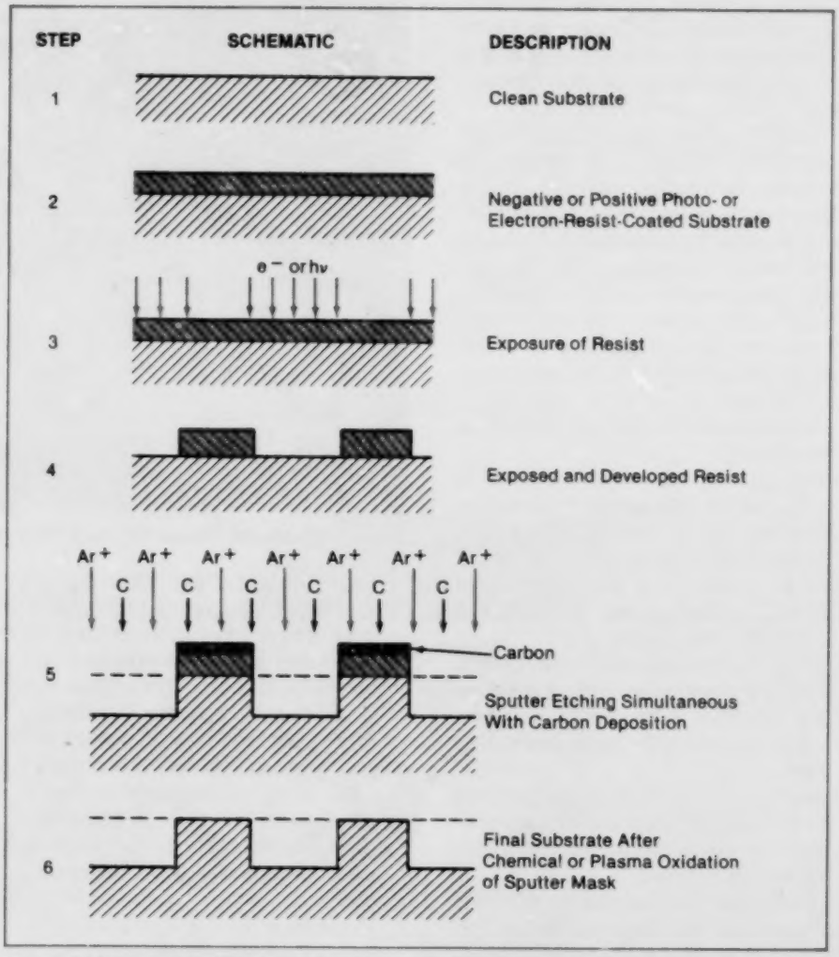


Figure 1. This Sputter-Etching Process replenishes the sputter mask with carbon to prevent premature mask loss.

The high sputter yield of the unmasked portion of the substrate prevents any net carbon-film buildup as does occur on the carbon-coated mask. After the sputter etching is completed, the remaining mask can be removed by conventional chemical resist-removal techniques or by oxygen RF plasma oxidation. Figure 1 shows the general sequence of steps as they modify the substrate to be sputter-etched. Figure 2 shows several configurations of ion sources that provide ion-beam sputter etching simultaneously with carbon sputter or vapor deposition.

Variations can be made to the described process such as the following seven:

1. An alternate sequence can be used to make a negative of the Figure 1 sequence by changing the sequence after step 4. The substrate and the developed mask could be sputter- or evaporation-coated with a very thin carbon film. The resist (plus its carbon coating) could then be chemically dissolved leaving a carbon film

where the resist was not present, and an uncoated substrate where the resist used to be, then continuing starting with step 5.

2. The sputtering ions can be other inert or noninert gases or free radicals.
3. The substrate can be rotated.
4. The arrival angle and energy of the bombarding ions and/or the carbon can be varied.
5. The resist can be either negative or positive and can be exposed by electrons, ions, visible light, or X-rays.
6. Sputter etching can be RF or ion-beam.
7. The ratio of carbon-atom arrival to removal from the substrate can be varied to control the rate of mask replacement from net etching to net deposition. This ratio can be varied during ion-beam sputter etching to achieve desired substrate or sputter-mask characteristics.

This work was done by Bruce A. Banks and Sharon K. Rutledge of **Lewis Research Center.** *Further information may be found in NASA TM-82873 [N82-28445/NSP] "Ion Beam Sputter Etching of Integrated Circuits and other Microelectronic Components" [$7]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 29]. Refer to LEW-13899.

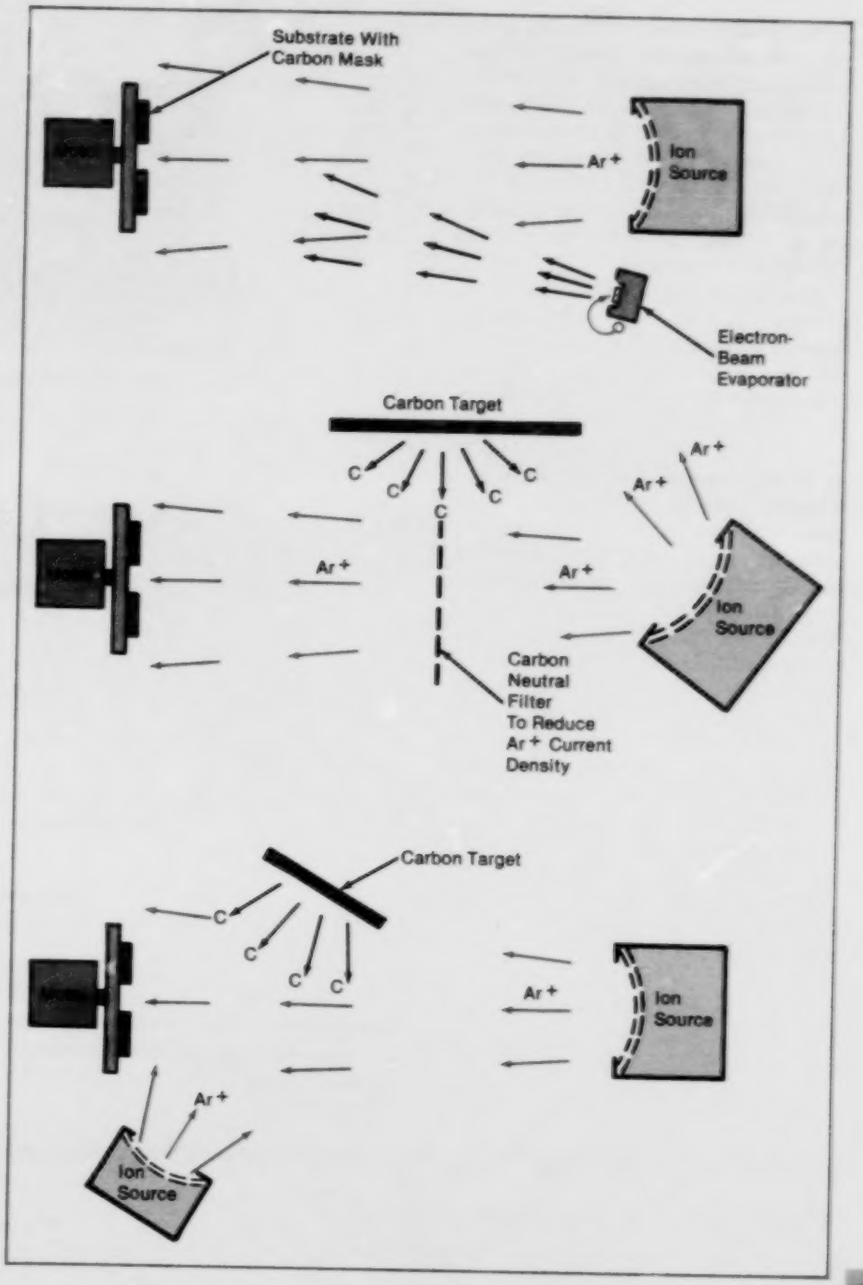


Figure 2. These **Ion-Source Configurations** can each be used to perform ion-beam sputter etching simultaneously with carbon sputter or vapor deposition.

Unitized Nut-and-Washer Assembly

A proposed fastener would be nonscratching and easy to install.

Lyndon B. Johnson Space Center, Houston, Texas

A combination nut, washer, and lockwasher would secure parts quickly without damaging metal finishes. The proposed fastener is intended for attaching leads and buses to studs on electronic equipment.

The conventional way of securing a lead is to attach it to a stud with a flat washer, a lockwasher, and a nut. The flat washer is placed between the lead terminal and the lock washer to prevent the latter from cutting into the plated finish of the terminal.

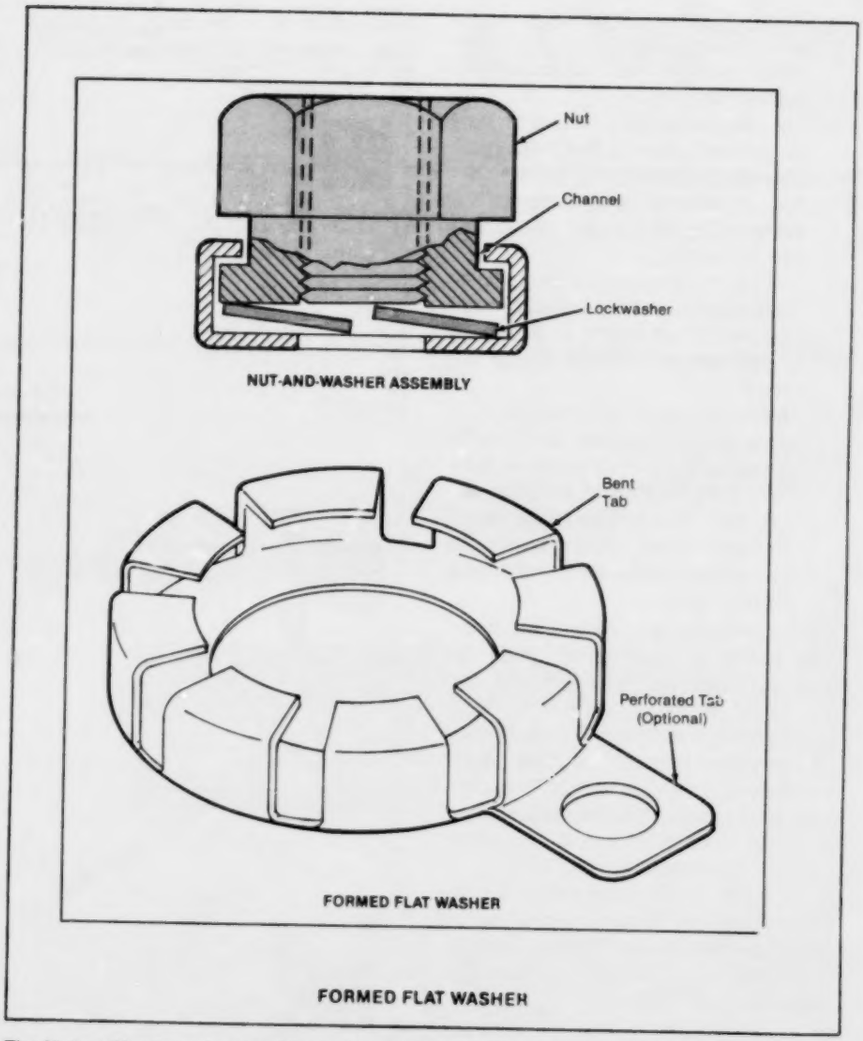
The manual assembly of the three parts is tedious, especially with small-diameter studs. It is also prone to error when the flat washers are made of corrosion-resistant steel (CRES) and are used in conjunction with shim washers

made of nickel-plated copper. The shims are used as spacers between multiple connections on the same stud or to bring terminals on adjacent studs to the same level. They can easily be confused with CRES washers, which have lower electrical conductivity. Thus, the accidental substitution of a CRES washer for a copper shim could cause overheating and damage to the equipment.

Since the proposed fastener would be attached as a unit they would reduce assembly time and eliminate the need to stock separate CRES washers, thereby also eliminating erroneous substitution for the lower resistance shims.

The nut on the proposed fastener would be made by machining a circumferential channel on hexagonal, nonlocking nut (see figure). The outer portion of the flat washer would be cut away in a pattern to make tabs. The washer would be attached to the nut by bending the tabs into the channel. The width of the channel would have to be equal to the free height of the lockwasher, which would be sandwiched between the nut and the flat washer. Tightening the nut on a stud would automatically compress the lockwasher, which may be a helical locking spring or internal-tooth type.

This work was done by Peter J. Rossi of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20903



The **Nut and Lockwasher Are Captured** by the bent tabs of a flat washer in this concept for a unified fastener. The optional perforated tab on the flat washer would allow easy tagging and storage.

Composite Fasteners

Flexible fasteners are easily installed and removed by hand.

Langley Research Center, Hampton, Virginia

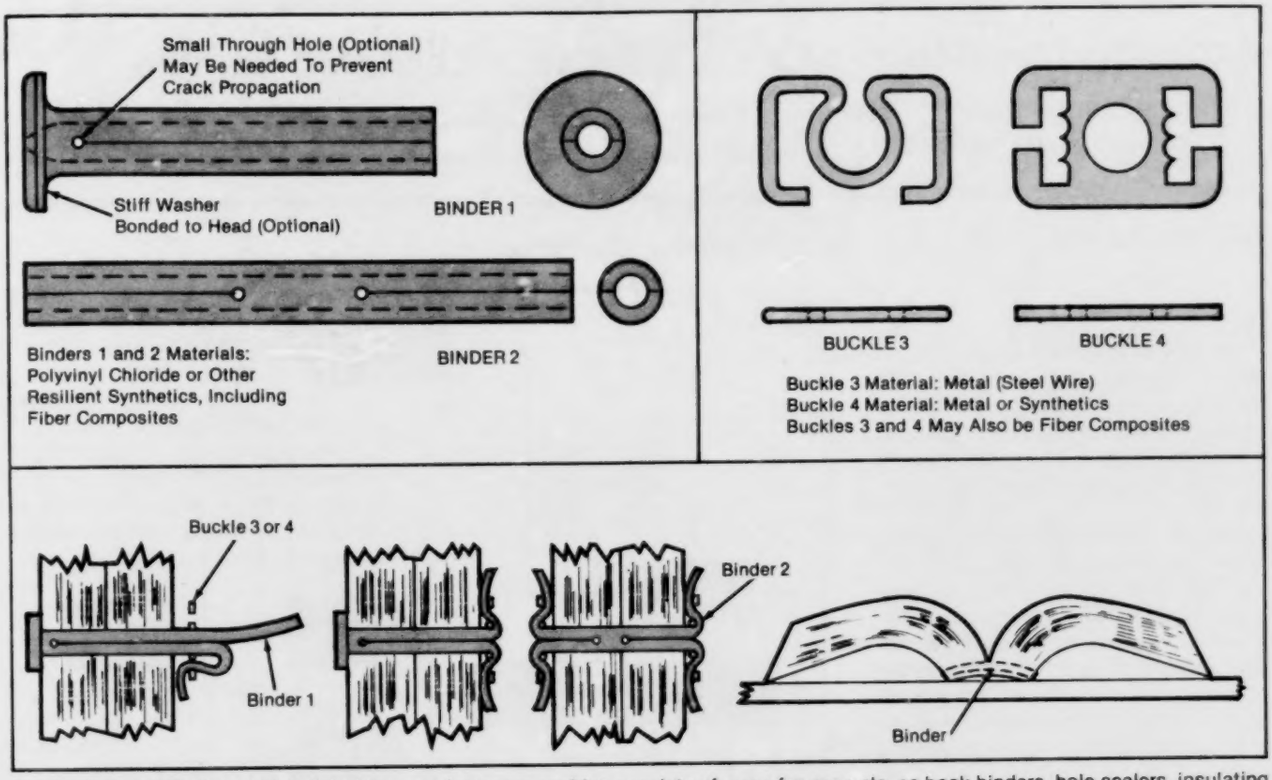
Flexible composite fasteners made of polyvinyl chloride or other resilient synthetic material are designed for joining together various materials which may vary slightly in thickness during use. The fasteners are easily installed and removed by hand and maintain approximately the same tension in bonding the materials together, regardless of the subsequent movements of the materials.

A fastener of this type is designed to join or bind structures requiring only a snug all-around fit in the lateral and longitudinal directions of the fastener shaft. The fastener, being flexible, is also capable of yielding under loading in all directions but will still bind the structures with initial tightness and will maintain its circular shape in the shaft before and after structural movement.

One application of this fastener concept is the binding together of paper to make a book (see figure). The flexibility of the fastener allows the book to open wider, and the snug fit between the fastener shaft and the circular holes at the edge of the book will keep the pages evenly spaced and aligned. Also, more bearing area is provided between the paper and the fastener shaft to resist page tearout. The fastener shaft can be cut easily with scissors or a knife and can be produced in different sizes.

Another application of this fastener is as a hole sealer. Binder 1 and buckle 3 or 4, if produced in various sizes, can be used as a fluid sealer. The head and the shaft of the binder could block a hole in a structure completely to form an airtight seal.

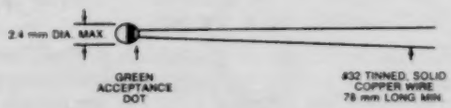
With the proper selection of dimensions and materials, the fastener can also



The **Design and Choice of Material** of the new fasteners enables a variety of uses; for example, as book binders, hole sealers, insulating fasteners for electronic circuitry, or break-away energy-absorbing fasteners for vehicles in crashes.

be used as an energy-absorbing breakaway fastener for fail-safe vehicles in crashes. The fastener shaft could be designed to yield and breakaway at a given load. It can be used also as an insulating fastener in electronics or as a fastener with minimal heat flow for transistor devices or other devices requiring such properties.

This work was done by Gim Shek Ng of **Langley Research Center.** *No further documentation is available.*
LAR-13058



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Acoustic Translation of an Acoustically Levitated Sample

A sample can be moved quickly from hot to cold regions in the levitation chamber.

NASA's Jet Propulsion Laboratory, Pasadena, California

An acoustic-levitation apparatus uses only one acoustic mode to move a sample from one region of a chamber to another. The sample can be heated and cooled quickly by translation between hot and cold regions of the levitation chamber.

Thus far, acoustic levitators have been tested successfully in chambers of uniform temperature. Because of the large mass of the furnace surrounding levitation cells, these chambers require a considerable amount of time to change their temperatures. Hence, they are unsuitable for containerless experiments requiring quick cooling of the processed sample.

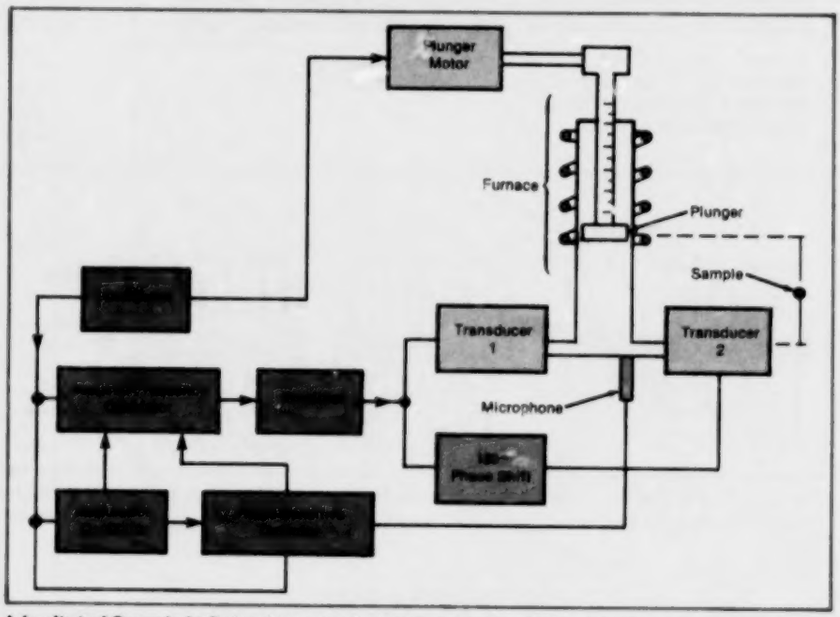
Samples can be cooled quickly in the system shown in the figure. A long, round cylindrical acoustic resonator is excited by two transducers positioned 180° apart at the cold end. For a uniform-temperature system, the resonance frequency decreases as the length of the chamber increases, according to the following equation for the normal-mode resonant frequency:

$$f(mnn_z) = (c/2a)[\alpha^2_{mn} + (n_z a/l_z)^2]^{1/2}$$

where c is the speed of sound, a and l_z equal the radius and length of the resonator, respectively, and α_{mn} is a constant depending on the values of m and n. For a real levitation system, this equation will be modified slightly by such perturbation effects as those due to the acoustic ports, waveguides, and temperature gradients.

By driving the transducers out of phase, one obtains maximum acoustic power coupled to the (102) resonant mode and nearly zero power coupled to various plane-wave modes that would interfere with the levitation forces. The (102) mode produces acoustic forces that position a sample at the center of the chamber. Thus, as the chamber is lengthened by raising the plunger, the central levitation position is raised, carrying the sample along with it.

The feedback system shown in the figure continuously adjusts the acoustic frequency to track the resonant mode as the chamber length changes and to compensate for the perturbations. The acoustic-oscillation frequency is modulated at a low frequency about the resonance value. A microphone measures the chamber acoustic-pressure signal, and a phase-sensitive detector measures the magnitude and sign of the received modulated signal. For a properly calibrated system, this detected modulation signal will be zero at the chamber resonance.



A Levitated Sample Is Raised into the furnace region by raising the plunger: The frequency of the sound produced by the transducers is adjusted by the feedback system to maintain the (102) resonant mode, which levitates the sample midway between the transducers and the plunger regardless of the plunger position.

When the resonance frequency changes due to the plunger motion or other causes, the detected modulation-error signal can be used to change the frequency of the oscillator to maintain continuously chamber resonance. The detected modulation signal can be fed back to the oscillator by analog or digital means.

With this system the sample would be heated and then cooled quickly by being inserted into the cool (lower) region of the resonator, raised into the heated region by the rising plunger, and then, after it had been processed at the desired temperature, quickly lowered to the cold region by the descending plunger. After the sample has cooled, it can be removed and replaced by a new sample.

In one of the variations of this system, the plunger would remain above the furnace to eliminate delays caused by the heating and cooling of the plunger. Another version uses a telescoping chamber instead of a plunger. When temperature uniformity of the sample is extremely important, the cylinder could be curved through the furnace region so that the sample will be almost completely surrounded by uniform radiant heat. Sample quick cooling can also be accomplished using other ($10n_z$) modes with $n_z > 2$. As n_z increases, the sample movement relative to the plunger motion can be increased, thus enhancing the quick-cooling process.

This work was done by Martin B. Barmatz and James L. Allen of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 50 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 29]. Refer to NPO-16675.

Acoustic Levitator Maintains Resonance

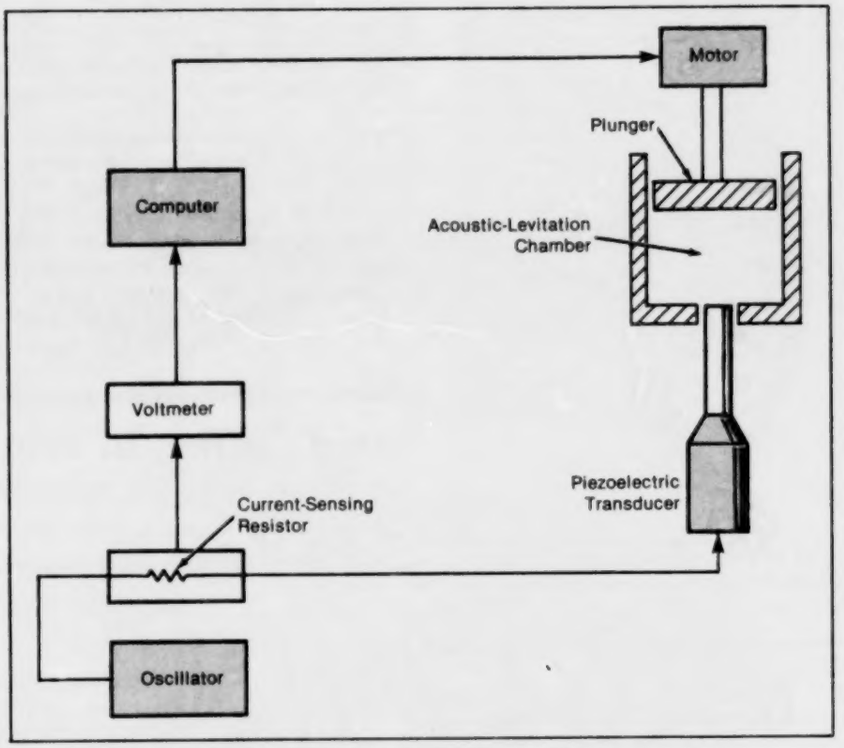
Transducer loading characteristics allow resonance to be tracked at high temperature.

NASA's Jet Propulsion Laboratory, Pasadena, California

An acoustic-levitation system automatically adjusts the sound frequency or chamber length to maintain the resonance necessary for levitation. Developed for containerless processing of materials at high temperatures, the system does not rely on microphones as resonance sensors, since microphones are difficult to fabricate for use at temperatures above 500 °C. Instead, the system uses the acoustic transducer itself as a sensor.

The resonance in the acoustic-levitation chamber affects the mechanical load on the transducer. This load, in turn, affects the electrical behavior of the device. Near the acoustic resonance, the transducer current reaches a minimum, and the voltage and impedance reach a maximum. By monitoring any of these parameters and adjusting the sound frequency (in a constant-length levitator) or the chamber length (in a constant-frequency levitator) accordingly, one can keep the chamber resonating as the temperature changes.

In a constant-frequency system, for example, a piezoelectric transducer is coupled to a cylindrical chamber (see figure). The chamber length is set by a plunger, the position of which is controlled by a computer. The transducer current is monitored via the voltage across a series resistor. The computer finds the resonant plunger position by searching among the currents measured throughout a small range of recent positions. The computer commands the plunger to dither about the new resonant (minimum current) position. This process repeats continuousiy. Therefore, as the chamber temperature changes during processing, the chamber length is continuously adjusted to maintain resonance and levitation.



The **Acoustic-Levitation Chamber** length is automatically adjusted to maintain resonance at a constant acoustic frequency as the temperature changes.

This work was done by Martin B. Barmatz and Mark S. Gaspar of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 49 on the TSP Request Card.* *NPO-16649*

Xenon-Ion Drilling of Tungsten Films

Many small, precise holes are produced simultaneously.

NASA's Jet Propulsion Laboratory, Pasadena, California

High-velocity xenon ions are used to drill holes of controlled size and distribution through the tungsten layer that sheaths the surface of a controlled-porosity dispenser cathode of a traveling-wave-tube electron emitter. This rapid, precise drilling technique could be applied to films of other metals and used in other applications where micron-scale holes are required. The method requires only a few hours, as opposed to tens of hours by prior methods.

A controlled-porosity dispenser cathode employs a barium/calcium/aluminum oxide mixture that migrates through pores in the cathode surface, thus coating it and reducing its work function. Present cathode-fabrication techniques result in nonuniform hole sizes and spacing and in poor hole quality. This causes the coating to become uneven, reducing the efficiency

of the electron emitter.

The first step of the new drilling technique is the fabrication of an electroformed nickel mesh or silicon mask containing holes matching those desired in the cathode. This mask then receives an outer carbon coating through bombardment by carbon struck from a graphite block by a beam of high-velocity ions formed from xenon gas (see Figure 1).

The coated mask is placed on the cathode. The mask is then bombarded by xenon ions (see Figure 2). Although these ions etch both the mask and the portions of the cathodes exposed through the holes in the mask, the portions of the cathode protected by the mask are not etched. The use of xenon increases the tungsten/carbon etch ratio over that attainable with other ions. The holes made in the cathode surface faithfully reproduce the pattern in the mask. In the initial application of this technique, 5-μm holes were produced in 12-μm-thick tungsten.

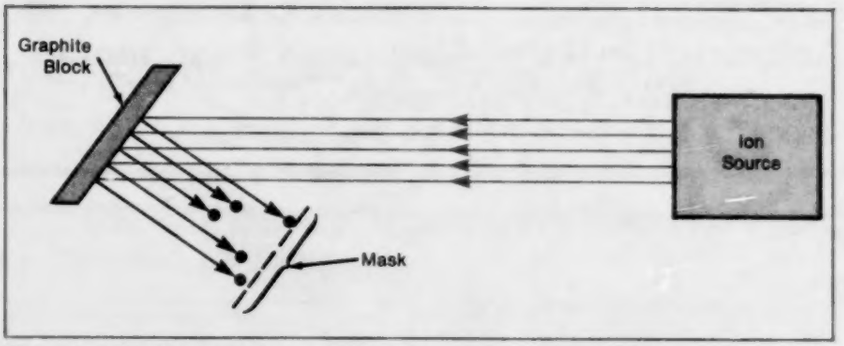


Figure 1. A **Hard Carbon Coating** is deposited on a mask. The mask is struck by carbon atoms dislodged from a graphite block by a beam of high-velocity xenon ions.

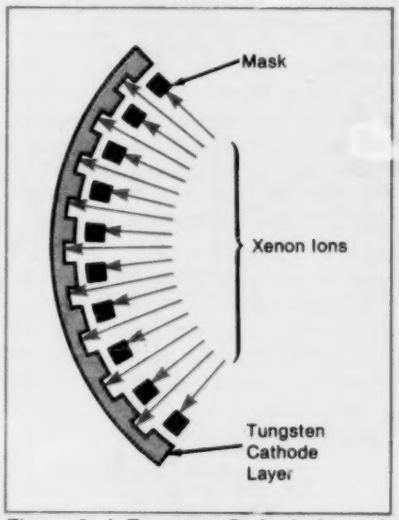


Figure 2. A **Tungsten Cathode Layer Is Etched** through the carbon-coated mask by xenon ions.

This work was done by Charles E. Garner of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 54 on the TSP Request Card.*
NPO-16626

Laser Cutting of Thin Nickel Bellows

The technique avoids the damage caused by the trimming of thin material on a lathe.

Marshall Space Flight Center, Alabama

A laser cutting technique produces narrow, precise, fast, and repeatable cuts in thin nickel-allow bellows material. This technique avoids the distortion, dents, and nicks produced in delicate materials during lathe trimming operations, which require high cutting-tool pressure and holding-fixture forces.

The laser cutting operation uses an intense focused beam to melt the material and an assisting gas to force the melted material through the part thickness, creating a void. When the part is rotated or moved longitudinally, the melting and material removal is continuous and creates a narrow, fast, precise, and repeatable cut. This technique can be used to produce cuts of specified depths less than the material thickness.

With argon as the assisting gas, a 400-W Nd: YAG laser has been used in three cutting operations on the multiple plies of a thin [0.014 to 0.018 in. (0.36 to 0.46 mm)] nickel-base alloy 718 used to fabricate the Space Shuttle main engine flex duct bellows. The operations were marking pass, seal weld trim, and ending trim. A "marking pass" operation places a narrow, shallow line on the outer bellows ply, running parallel to and at a specified distance from the bellows first convolution wall. A "seal weld trim" operation cuts through an existing electron-beam weld approximately 0.028 in. (0.71 mm) deep and 0.040 in. (1.0 mm) wide. This trim is a critical operation, because all nonfused ply material must be removed from one side of the weld while leaving a sufficient amount of weld nugget on the part for subsequent electron-beam welding without fusion of the remaining bellows plies. An "end ring trim" operation cuts through a one-ply end ring approximately 0.060 in. (1.5 mm) thick. This trim operation removes exess manufacturing stock from the bellows end ring and generates a surface that must comply with four drawing requirements.

This work was done by Craig L. Butler of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-29133

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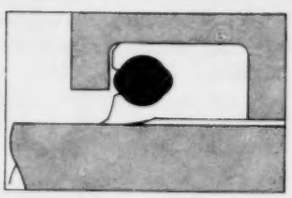

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Theoretical Foundation for Weld Modeling

Differential equations describe the physics of tungsten/inert-gas and plasma-arc welding in aluminum.

A report collects and describes the necessary theoretical foundation upon which a numerical welding model could be constructed for tungsten/inert gas or plasma-arc welding in aluminum without a keyhole. The governing partial differential equations for the flow of heat, metal, and current are given, together with boundary conditions relevant to the welding process. Numerical estimates for the relative importance of various phenomena and the required properties of 2219 aluminum are included.

This is apparently the first attempt to construct a single model that simultaneously incorporates realistic three-dimensional geometries and boundary conditions, while also predicting the moving phase-change boundary as determined by latent-heat considerations and calculated velocities in the weld puddle. Concentrating on the weld puddle, the report provides the necessary governing equations and associated boundary conditions that determine the temperatures and the flow of heat in the heat-affected zone of the workpiece, the shape of the puddle, and the flow of metal and current in the puddle.

The resulting model did not cover all aspects of welding in complete generality: At present, it would be premature to attempt to incorporate metal transfer from a consumable electrode, or welding rod or wire, plasma flow and heat transfer in the arc, and the much more complex aspects of weld-puddle shape for high-power-density welding practices that produce vapor cavities. Instead, the report is aimed at the modeling of autogenous, nonconsumable (tungsten) electrode gas- or plasma-arc welding without a keyhole — the kind of welding of particular importance in aluminum structures. While not all inclusive, the theory can be used to produce quantitative answers to questions that have not yet been addressed. These include the relative roles of stirring due to the variation of surface tension with temperature versus magnetohydrodynamic stirring in determining puddle shape and the effects of changes in arc pressure, velocities, and shear.

Because of the multiplicity of phenomena contained in the general case, the numerical modeling results will be difficult to interpret. Therefore, the value of such computations would be greatly enhanced by examining separate, simplified cases in which the various phenomena are treated in isolation. Results for such special cases will enhance general understanding and the interpretation of more general results. These results may reveal that some of the effects and phenomena included in the very general description may be of minor practical consequence and thus do not need to be included and that others are of greater importance than presently realized.

This work was done by S. C. Traugott of Martin Marietta Corp. for **Marshall Space Flight Center.** *To obtain a copy of the report, "Discrete Element Weld Model. Phase I: General Model of a Weld Puddle Without a Cavity," Circle 48 on the TSP Request Card.*
MFS-27095

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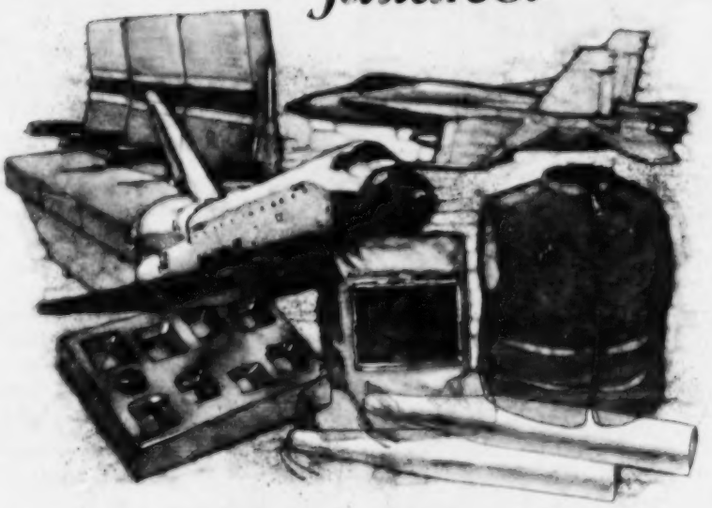

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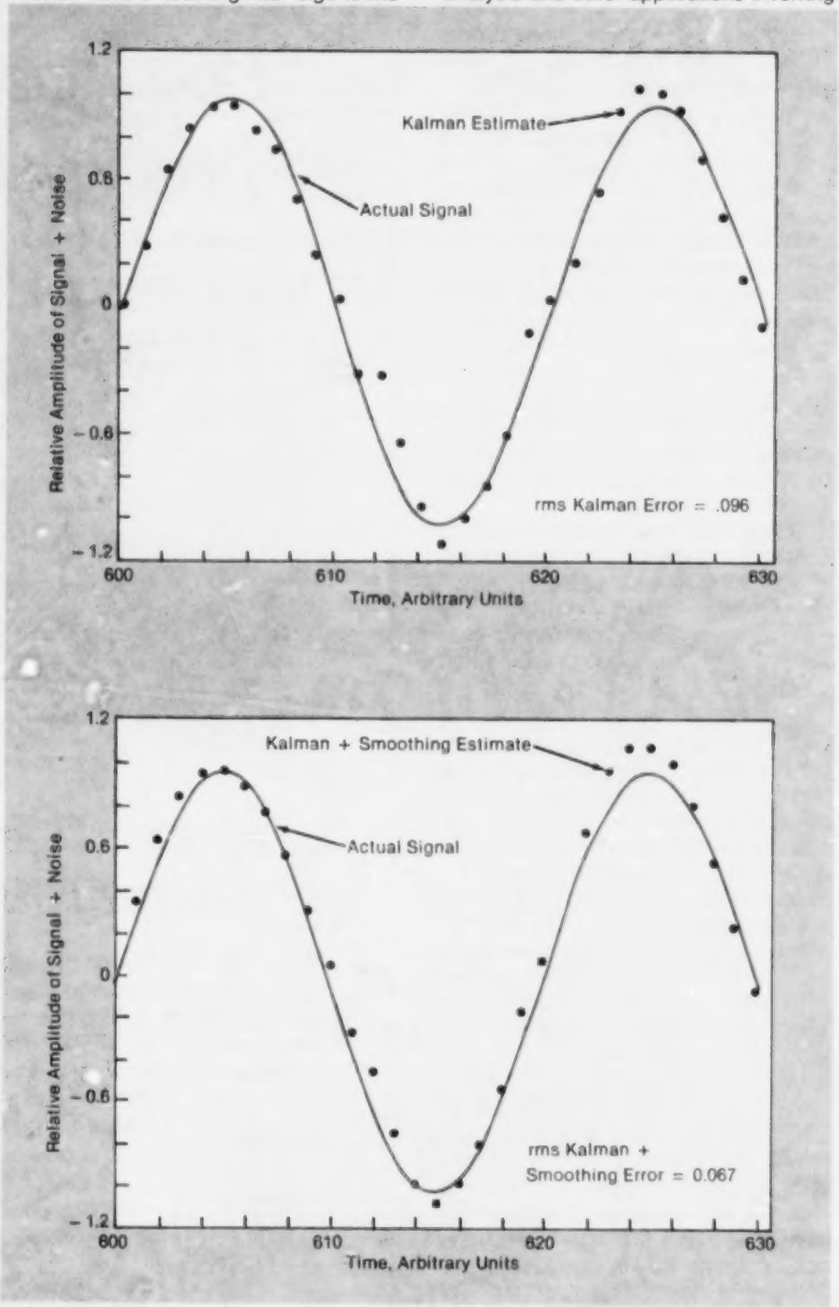
Digital Filter Separates Signal From Noise

The variance of the signal-estimation error is minimized.

Lyndon B. Johnson Space Center, Houston, Texas

A mathematical technique extracts best estimates of a signal component from periodic digital samples of a signal plus noise. The technique combines Kalman- and smoothing-filter algorithms to minimize the mean-square estimation error based on past, present, and predicted samples of the signal plus noise. The technique will be useful in image analysis and other applications involving



Estimates of a Signal extracted from signal plus noise were made by Kalman filtering alone (above) and by Kalman-plus-smoothing filtering (below). The rms error is smaller with smoothing, signifying a better estimate.

the processing of noisy signals.

The objective is to find the signal x(t) in a received or measured waveform z(t) = x(t) + s(t), where t = time and s(t) = the noise component. In Kalman filtering, samples of the waveform are taken at the present and at past times t_i, t_{i-1}, t_{i-2}, etc. A Kalman filter provides an optimal estimate of the signal components of the samples, provided that the autocorrelation functions of the signal and additive noise are known. The task in Kalman filtering is to obtain the difference equations for the signal and noise dynamics that give the correct autocorrelation functions for the signal and noise.

The difference equations generally involve polynomials of finite order, the coefficients of which yield the Kalman-filter coefficients. The Kalman-filter equations provide the best estimate for $x(t_i)$ based on all the data $z(t_j)$ received prior to the present time, t_i. It is possible, however, to improve the estimate by using predicted data for times beyond t_i. These estimates are provided by the smoothing equations, which use the initial output of the Kalman filter to make the predictions.

Difference equations have been derived for the first through fourth orders. In one test of the technique, second-order difference equations were used on a signal with an autocorrelation function consisting of a cosine multiplied by an exponential and an exponential noise autocorrelation function. The figure shows the Kalman (alone) and Kalman-plus-smoothing estimates for this case. The rms error was 30 percent less with smoothing.

This work was done by William M. Lear of TRW, Inc., for **Johnson Space Center.** *For further information, Circle 4 on the TSP Request Card.*
MSC-20914

Adaptive Quantizer for Burst Synthetic-Aperture Radar

Unneeded bits are discarded to facilitate computation.

NASA's Jet Propulsion Laboratory, Pasadena, California

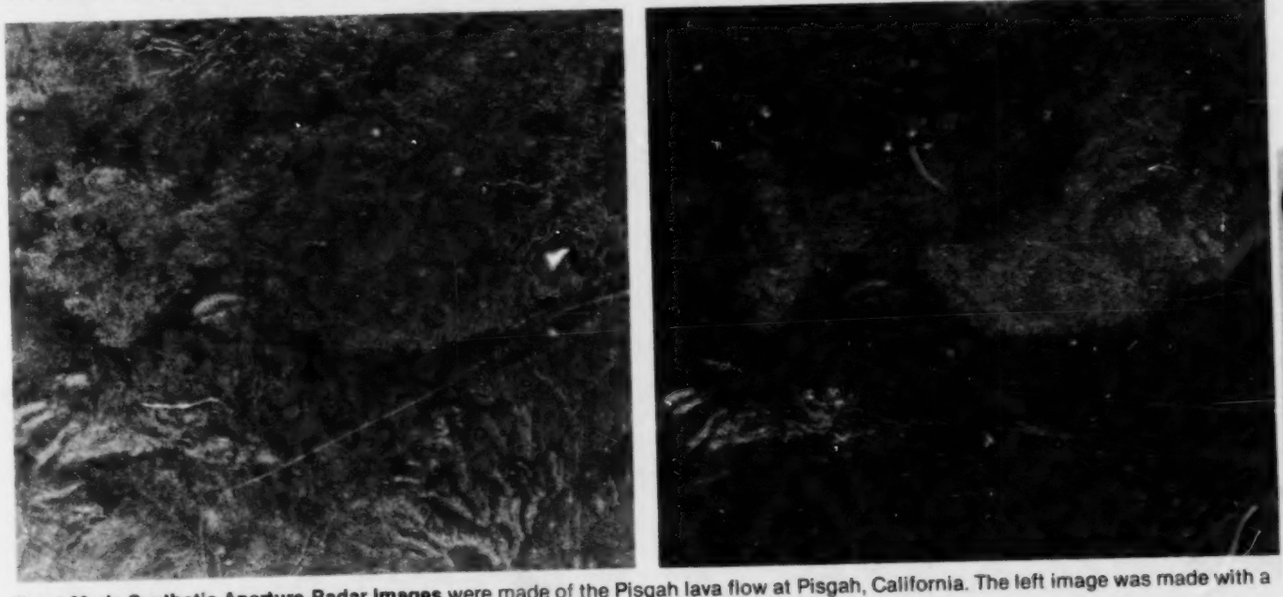
An adaptive quantizer for burst-mode synthetic-aperture radar reduces the data rate of the return signal. The device, called a block floating-point quantizer (BFPQ) is basically an analog-to-digital converter that covers a wide dynamic range and discards appropriate lower order bits. The BFPQ is, in effect, a digital approximator with automatic gain control.

The BFPQ moves the floating-point marker (i.e., the decimal point) in the binary representation of signal data in accordance with the perceived dynamic range. The available step sizes are thus limited to multiples of the underlying smallest quantization step (represented by the lowest order bit). The BFPQ retains only the first K most significant bits of the signal; an (L,K) BFPQ is one that does K-bit quantization of a signal that is originally quantized to L bits. For example, an (8,2) BFPQ that receives a signal near the middle of its dynamic range might retain the 3rd and 4th or the 4th and 5th bits.

To design a BFPQ, it is necessary to select optimally the dynamic range $2X_{max}$ and the number, K, of quantization bits of the L available. This requires consideration of the quantization error and its contribution to noise. Of course, the thermal noise contribution must also be considered, and the combined effects of both noise sources on the overall signal-to-noise ratio must be determined.

The quantization error is simply the difference between the actual signal level and its binary approximation. The BFPQ selects the K contiguous bits for the present burst on the basis of the signal received during the previous burst. The selection does not change during a burst, even when the signal goes above or below the present K-bit range. When the signal changes drastically in this way during a burst, an incorrect gain is selected.

The BFPQ concept has been tested



Burst-Mode Synthetic-Aperture-Radar Images were made of the Pisgah lava flow at Pisgah, California. The left image was made with a 1-bit (nonadaptive) quantizer. The right image was made with an (8,1) block floating-point quantizer.

numerically and experimentally. The figure shows a burst-mode synthetic-aperture-radar image processed by 1-bit uniform (that is, nonadaptive) quantization and by (8,1) adaptive quantization. The adaptively processed image shows an improvement in dynamic range. Other potential applications for the BFPQ include speech compression and picture-data compression.

This work was done by Tae H. Joo, Daniel N. Held, Rolando L. Jordan, and Fuk K. Li of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 98 on the TSP Request Card.*
NPO-16582

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Autonomous Orbital Calculation for Satellites

An onboard orbital navigation system would reduce dependence on Earth-to-satellite links.

A report discusses the mathematics of a proposed navigation subsystem that would keep a geostationary satellite in its proper orbit without ground control. The subsystem uses data from Earth and Sun sensors to activate thrusters for station-keeping maneuvers. With sensors already on satellites for determining attitude, the subsystem should be able to maintain the satellite within 3° of a specified equatorial longitude for up to 3 months. With more accurate sensors, the subsystem should be able to maintain the orbit within 0.1°.

The key parameter for maintaining the orbit is the angle formed between two lines extending from the satellite, one to the center of the Earth, the other to the center of the Sun. This angle is independent of the satellite attitude and therefore is not perturbed by errors in the attitude-sensing and attitude-control subsystems. The angle is computed from the inner product of the satellite-to-Earth and satellite-to-Sun vectors measured by the satellite Earth and Sun sensors and the solar-array drive potentiometer.

A time series of measurements is required to determine the orbit, especially since errors need to be averaged or filtered out as much as possible. Position information at different times is related through the orbital equations of motion. As they are acquired, the measurements

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are processed by a sequential, extended Kalman filtering algorithm; therefore, the measurements need not be stored. The equations assume that errors can be modeled as Gaussian noise so that the system is modeled as a whole by a stochastic differential equation.

Assuming a set of typical orbital parameters and angle measurements every 30 minutes, the authors conclude that station-keeping maneuvers are likely to be the major contributors to error. Such maneuvers are infrequent, however. The numerical integrator should be the next largest source of error. This type of error is a result of the rounding off imposed by the limitations of the onboard computer and could be reduced by improving the integration algorithm. Two additional ways of improving performance include adaptive filtering and data compression.

This work was done by Kenneth D. Mease, Mark S. Ryne, and Lincoln J. Wood of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "An Approach to Autonomous Onboard Orbit Determination," Circle 79 on the TSP Request Card.*
NPO-16532

Decluttering Methods for Computer-Generated Graphic Displays

Symbol simplification and contrasting enhance the viewer's ability to detect a particular symbol.

A report describes the experiments designed to indicate how various decluttering methods affect the viewer's abilities to distinguish essential from nonessential features on computer-generated graphic displays. The results indicate that partial removal of nonessential graphic features through symbol simplification was as effective in decluttering as the total removal of nonessential graphic features.

It had been hypothesized that search time is proportional to the number of visual features present in a display. Based on this hypothesis, the total removal of nonessential features would yield the most rapid search. The search would take longer if decluttering is done by contrasting (in which nonessential features remain on the display but are reduced in line width and intensity) than if it is done by simplification (partial removal of nonessential features). Similarly, search time would be greater when graphic products are displayed against a map background than without this background. This hypothesis was tested in a study in which the participants' task was to count the number of a particular class of displayed symbols as decluttering methods and map backgrounds were varied.

The hypothesis was supported in part: The total removal of extraneous symbols and simplification of these symbols facilitated search speed and accuracy relative to contrasting and no decluttering, while contrasting facilitated performance relative to no decluttering. In these cases, fewer graphic features were present after removal and simplification than after contrasting.

However, the hypothesis is contradicted by several aspects of the data:

- Removal, which produced the greatest reduction in visual features, did not significantly reduce the response time in comparison to simplification.
- Map backgrounds, which contained high levels of graphic features, did not yield a main effect upon response time; instead, they caused an increase in performance after contrasting and a decrease in performance after simplification. These results therefore indicate that the hypothesis is only partially true.

The degree to which decluttering makes essential graphic information distinctive, rather than the absolute number of visual features per se, appears to be critical in determining response time. Thus, even though more graphic information remains after simplification than after removal, both decluttering operations produce a small set of highly distinctive symbols that can be readily located. The presence of another set of smaller, simplified symbols after simplification does not increase the response time relative to removal because these simplified symbols readily stand out against the essential symbol set and vice-versa. Similarly, map backgrounds appear to increase the color contrast between essential and nonessential symbols. Thus, in contrasting, the presence of additional graphic features (for example, terrain markings and road symbols) enhances the discrimination between single-line and double-line-width symbols.

These results not only suggest a theoretical framework for studying decluttering, but also demonstrate the viability of simplification and contrasting as decluttering methods. Both of these methods still allow users to perceive interrelationships among the various graphic display elements, yet enable essential graphic elements to be perceptually distinct. Although simplification is the more effective of these two methods, contrasting is preferred by users. If users are given the option to declutter hierarchically, the first level of decluttering could be contrasting, followed by simplification or removal or both at the second level.

This work was done by E. Eugene Schultz, Jr., of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Decluttering Methods for High Density Computer-Generated Graphic Displays," Circle 40 on the TSP Request Card.*
NPO-16733

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152 Rotating Apparatus for Isoelectric Focusing

Small-Portion Water Dispenser

Pressure is regulated and flow is timed to control the amount dispensed.

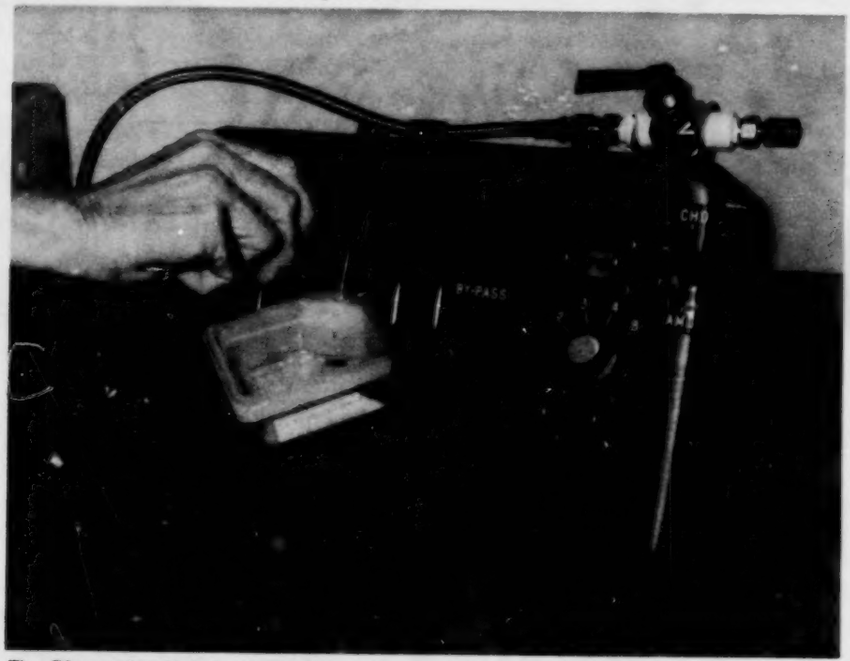
Lyndon B. Johnson Space Center, Houston, Texas

A dispenser provides a measured amount of water for reconstituting dehydrated foods and beverages. The dispenser holds the food or beverage package while it is being filled with either cold or room-temperature water (see figure). Other uses might include the dispensing of fluids or medicine.

A pressure regulator in the dispenser reduces the varying pressure of the water supply to a constant pressure. An electronic timer stops the flow after a predetermined length of time. The timed flow at regulated pressure ensures that a controlled volume of water is dispensed.

The user inserts a package to be filled in a nest in the dispenser and adjusts the dispensing needle to pierce the septum of the package. The "power" button is then depressed and a selector valve is turned to the cold ("CHD" in the figure) or room-temperature ("AMB" in the figure) position. After choosing the amount of water — 2, 3, 4, or 8 ounces (59, 89, 118, or 237 milliliters) — the user depresses the "fill" button. When the dispenser has filled the package, the user disengages the needle and removes the package.

This work was done by Jack C. Joerns of Technology Inc., for **Johnson Space Center.** *For further information, Circle 74 on the TSP Request Card.*
MSC-20534



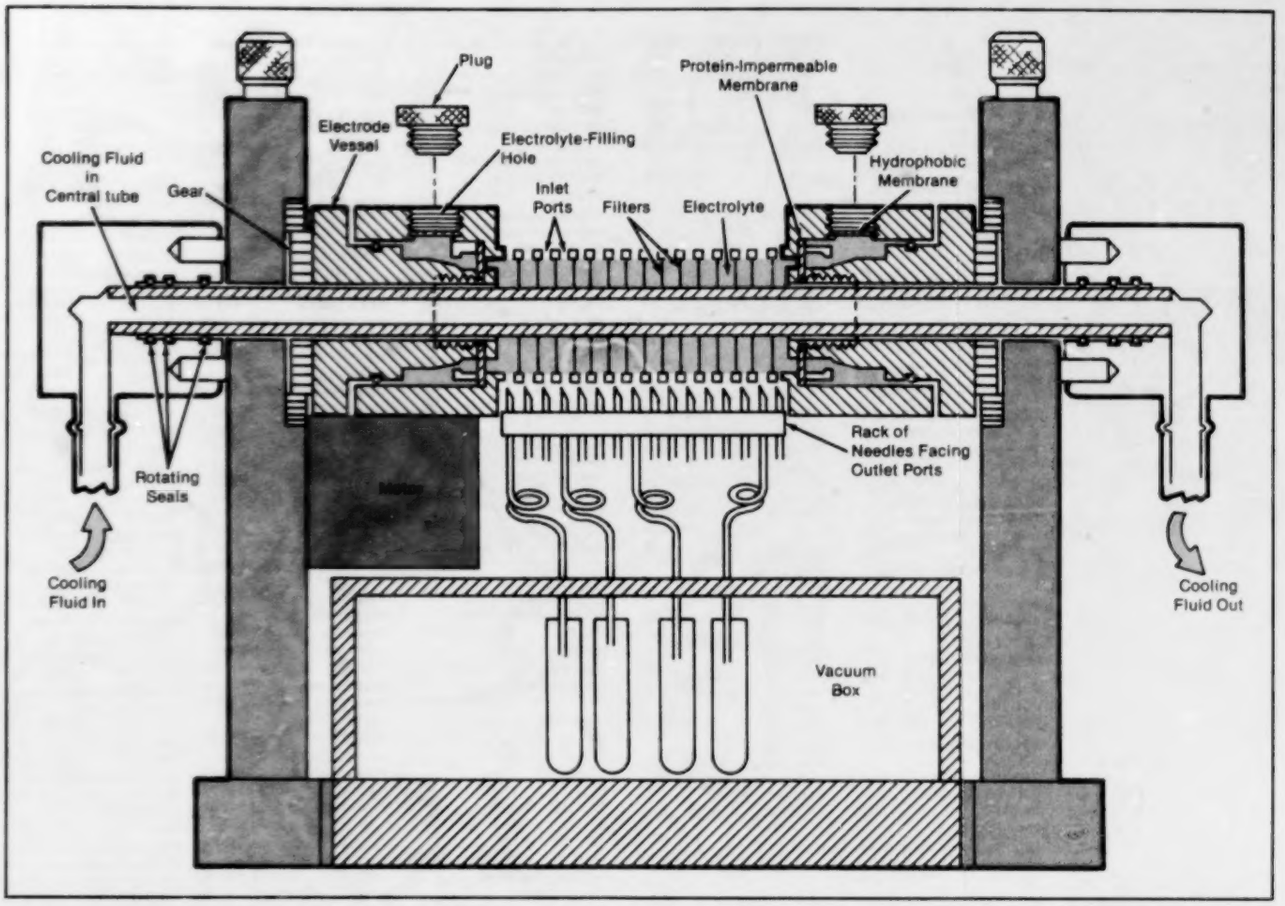
The Dispensing Unit is shown here in operation with the dispensing needle about to penetrate a plastic food package.

Rotating Apparatus for Isoelectric Focusing

The remixing of separated fractions is prevented.

Marshall Space Flight Center, Alabama

An improved isoelectric focusing apparatus helps to prevent electro-osmosis and convection, both of which cause the remixing of separated fractions. The fractionating column is segmented and rotated about a horizontal axis: Only the combined effects of both features are fully effective in making good separations.



The **Improved Isoelectric Focusing Column** is rotated and segmented to prevent the remixing of separated protein fractions.

Isoelectric focusing is an electrophoretic process in which mixtures of proteins in an electrolyte are separated into components, each of which migrates to an equipotential surface or region in which it comes to rest. The separated fractions are then withdrawn individually for further analysis.

The improved apparatus (see figure) is slowly rotated continuously or rocked (at a rotational amplitude of at least 180°) about its horizontal axis so that the average gravitational vector experienced by the fluid is zero and convection is therefore suppressed. Electro-osmosis is suppressed and convection is further suppressed by separating the column into disklike compartments along its length with filters.

The filters may be, for example, monofilament nylon screens of fine porosity offering some resistance to bulk fluid convection but allowing the free passage of electric currents and protein molecules. Each protein can therefore move into one or more compartments, the contents of which are closest to its isoelectric point (the electric potential at which it comes to rest).

Each compartment has an inlet and an outlet port. The column is filled by taping the outlet ports closed, then manually injecting the fluid to be fractionated through the inlet ports. The inlet ports are taped closed before beginning rotation and applying the axial electric field.

The column would normally be made of glass or a transparent plastic like poly(methyl methacrylate). If the proteins are colored, the separation process can be viewed. The process can also be observed by an increase in the electrical resistance of the fluid along the column. Isoelectric focusing is preferably done at constant power, with the electric field gradually increasing from 5 to 10 V/cm up to 100 to 200 V/cm as the resistance increases.

The electric field is introduced by platinum electrodes at each end of the column and conducted by an electrolyte to the end compartments. Protein-impermeable membranes separate the protein-containing electrolyte of the column from the electrode electrolyte. A hydrophobic membrane allows the venting of electrolytically generated gases without spilling fluid.

Experiments have shown that the dimensions of the apparatus are not critical. Typical compartment and column volumes are 2 and 40 ml, respectively. Rotation speeds can lie between 3 and 30 rpm.

This work was done by Milan Bier of the University of Arizona for **Marshall Space Flight Center.** *For further information, Circle 76 on the TSP Request Card.*

Title to this invention, covered by U.S. Patent Nos. 4,204,929 and 4,362,612, has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the University of Arizona, Tucson, AZ 85721.
MFS-26012

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WE'RE FIGHTING FOR YOUR LIFE

American Heart Association

A FRAMEWORK FOR ACTION:
Improving Quality and Productivity in Government and Industry

The following recommendations were drafted at the 1984 NASA-sponsored "Symposium on Quality and Productivity: Strategies to Improve Operations in Government and Industry." They represent the collective wisdom of the more than 650 top executives from major American corporations, government agencies and universities who attended the symposium, which focused on the challenge of improving quality and productivity through effective managerial practices.

The major findings of the symposium are organized into nine themes, six of which were presented in the Fall and Winter 1985 issues of NASA TECH BRIEFS. In this issue, we conclude our presentation with themes seven through nine.

Each theme encompasses a set of recommended actions and management practices that have been shown to contribute to high quality and productivity— organizational imperatives in this era of the increasingly competitive global marketplace.

THEME 7: Modernization for Survival: Encouraging New Technology

Being a leader in research and development has been the key to keeping America competitive and in the forefront of technology. Although modernization involving new equipment and techniques is often difficult to justify on a return-on-investment criterion, management needs to have a philosophy that encourages new technology. Management also needs to have training plans for introducing new technology, to lessen the social impact on individuals.

> "Effects of technology are not instantaneous, but there is a competitive imperative to use the most productive technology available . . . most of foreign competition strength is application of the newest technology." (Fred Garry, General Electric Company)

New technology is making inroads on all fronts—office automation, new manufacturing equipment and innovative processes. New products appear daily and one company's new product becomes part of the next company's new process.

Office automation, the technology with the greatest impact on white collar productivity, has taken hold in the United States at a much faster pace than factory automation. In general, the equipment costs less, it can be introduced piecemeal and, most important, the fundamental technologies are already available. Any organization with a desire to automate office procedures can find a reasonable selection of affordable equipment on the market. Experience has indicated sizable savings. F. Giannantonio, Avon Products, noted a positive return on investment in just one year:

> "We measured indirect savings on productivity gains of 23 percent for management/professional staff and 53 percent for our secretarial/administrative staff."

But new technology means more than a way to do something faster or cheaper. It means social change and changes in the way work is organized and managed. Obtaining the full benefits of technology requires cooperation.

> "Once the employees, their unions, and our management team joined hands, that new technology really began to pay off." (Garry)

Recommendation 7.1 Plan for the Technical and Social Impact of Technology

Careful planning is necessary to insure that the potential benefits of new technology are realized. These plans must not only address changes in work methods and procedures, but also in how work is organized and managed, and how employees who operate and maintain equipment will be affected.

In older plants, according to Garry, successful introduction of new technology requires open, honest, two-way communication between management and employees and a commitment to retraining. In G.E.'s experience, many low-skilled workers have been successfully trained to handle high-technology jobs, thereby minimizing worker dislocation.

In white collar organizations, information technology will dramatically alter patterns of social interaction and access to information. This will lead to power shifts in the organization that could have profound consequences if not anticipated. William Pfeiffer of ITT discussed the "electronic cottage" concept, an extreme case of decentralization. Stimulated by the increased power and portability of computers, people will be able to work in their homes or other locations physically separated from the central organization. Widespread application of this concept will not only alter work practices but will create major organizational and even social changes.

> "Clearly, we're in for some profound changes, in both technology and office life . . . We must rethink our procedures and organizations." (Pfeiffer)

Recommendation 7.2 Stimulate Modernization Through Government Support and Incentives

Government has played an important role in the technology introduction process and should continue to do so. John Mittino described DoD's manufacturing technology program aimed at introducing new technology into the production environment. He stressed the importance of current DoD initiatives designed to share dollar savings resulting from a defense contractor's productivity-oriented capital investment, through efforts such as its Industrial Modernization Incentives Program.

The impact of such programs can be seen in success stories like that of General Dynamics, manufacturer of the F-16 fighter.

Willie Livingston of General Dynamics cited technology-based productivity improvements that have reduced the number of man-hours required to build an F-16 from 110,000 in 1979 to less than 30,000 in 1983. Overall, the F-16 program, stimulated by government incentives, will produce savings to DoD in excess of $1 billion.

Robert Walquist of TRW, Inc. gave another example of government/industry cooperation. He described the joint efforts of NASA and TRW to make the Gamma Ray Observatory spacecraft program a model for more productive ways of doing business. The program has already implemented a series of productivity macro-goals to lead company, sub-contractor and individual employee productivity increases. TRW's efforts cover both team building and the use of new technology. With the use of mini computers they have developed a common government-contractor database which has reduced the need for reporting. Through video conferencing they have increased communications and reduced travel costs.

Recommendation 7.3 Maximize Computer-Related Technology

White collar operations in industry and government are benefitting from computer/communications technologies. In aerospace firms such as Lockheed Missiles and Space Company, computer-aided design and manufacturing (CAD/CAM) are increasingly viewed as a means of reducing the labor content of products and improving product quality. In the future, these technologies will provide a way to cope with a projected shortage of skilled engineers and technicians. Lockheed's Fred Oder reported productivity savings from CAD ranging from 36 to 73 percent when compared to the cost of manual design.

While advances in office automation are occurring daily, the major office productivity breakthroughs have not yet occurred. Major gains await improved component compatibility and the convergence of computer and telecommunications technologies. William Pfeiffer of ITT points to three main concerns and needs of users that must be satisfied if office automation is to fulfill its promise. First, there is a need for easily understandable software triggered by English language commands. Second, the user needs an integrated package of hardware, software and communications technology. And finally, the most difficult need to satisfy is the standardization of system architecture. Knowledgeable managers can influence hardware and system vendors by communicating these requirements. Until these needs are met, the office automation contribution to quality and productivity improvements will continue to be less than optimum.

"The office of the future has not yet arrived... the technologies necessary to create it have been around for about ten years... what's missing is the 'glue'—the systems architecture that allows equipment from different vendors to work together... In other words, we have an electronic Tower of Babel." (Pfeiffer)

THEME 8: Maximize Human Capital: Developing Strategies to Improve Education and Training

Basic to productivity is education and training; it defines and develops the quality of human resources for the future. We have fallen behind in educational achievements and in the number of engineers graduating on a per capita basis. Improvement in national productivity and competitiveness depends on new strategies for the training, education and social conditioning of our most important natural resources—our people.

"Human capital is our most valuable national resource. It is insufficient to try to discuss productivity without discussing education which defines and develops the quality of human resources for the future." (Owen B. Butler, Procter & Gamble)

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Over the past several years, business and government leaders have noted a decline in the basic preparation of our young people to meet the diverse challenges and complexities of our fast-changing society. Blame is commonly put on the public school system, but family, school, the community, government and industry must all share responsibility.

According to Butler, industry spends approximately $30 billion annually on remedial and continuing education to make up for educational deficiencies in its work force. Schools, from the primary grades through college, must consider how to adapt their curricula, not just to the ever-changing job market but, equally important, to an ever-changing society. In this effort, the family, community, government and industry each have roles and responsibilities in guiding schools and motivating and educating young people for more productive lives. Each group must bear the responsibility and give it high priority.

Recommendation 8.1 Inform Educators of Required Job Skills

In the past, new employees entering the work force generally worked at low skill tasks on narrowly defined jobs that were relatively easy to learn. Today, employees are required to perform a broad range of tasks. They are expected to operate and maintain equipment, perform administrative tasks, participate in goal-setting and budgeting, and work in groups and teams that are self-directed and guided by principles rather than detailed procedures. Even people with strong educational backgrounds require a large amount of training to perform in this situation.

However, employees who lack a strong foundation in literacy, numbers skills and, above all, the ability to learn require even more training. Industry should bear the responsibility for specific job training, but our educational system must provide students with the basic skills required for employability in today's business environment.

Recommendation 8.2 Encourage Increases in the Number of New Scientists and Engineers

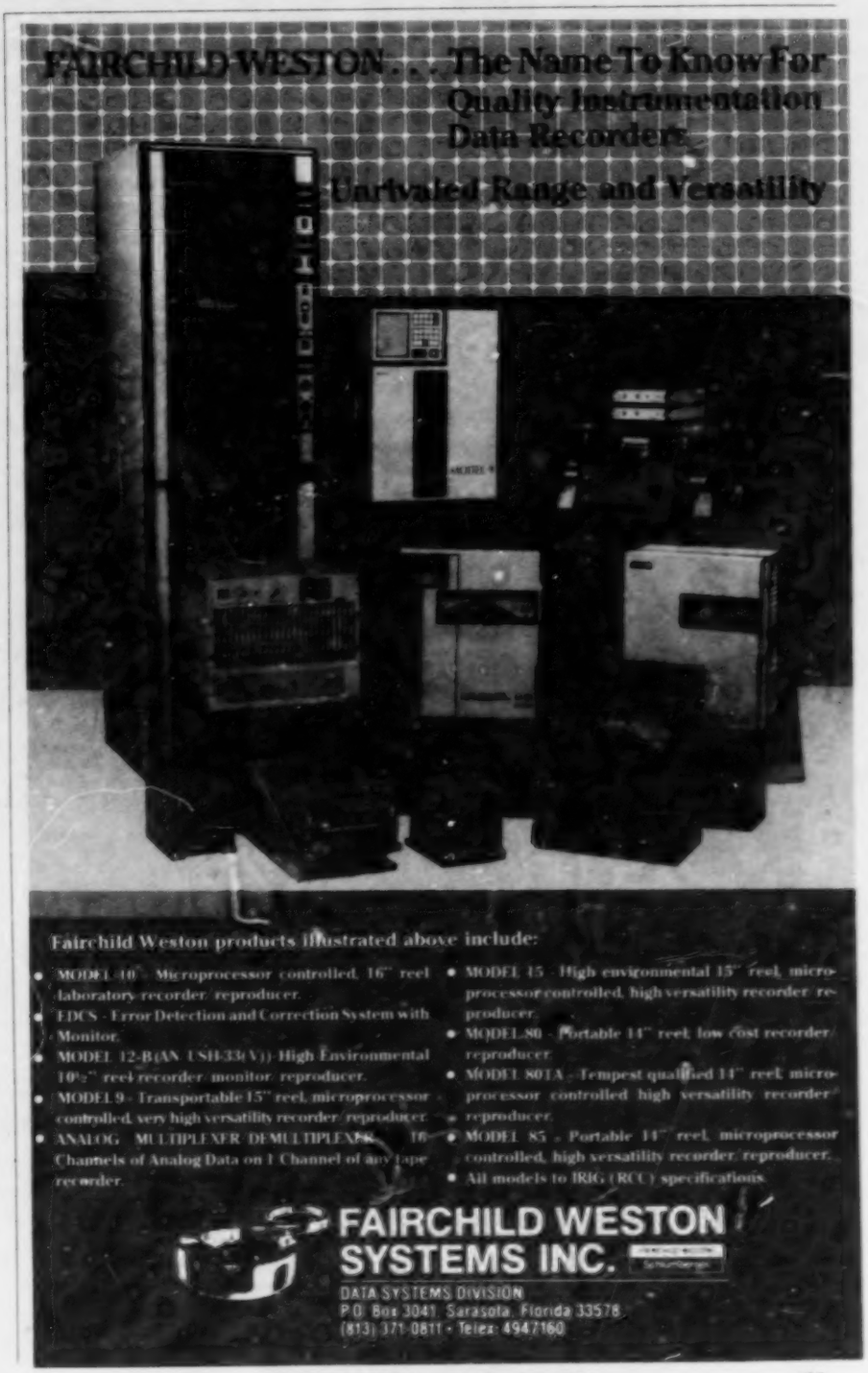
Industry should work closely with colleges to insure that scientists and engineers receive broad training, and should provide incentives that will attract them to manufacturing careers. The United States is falling behind in the number of new scientists and engineers compared with our competition.

> "In 1982, engineering and science accounted for only 20 percent of all bachelors degrees earned in the United States. This compares with 25 percent of all such degrees earned in Japan, 34 percent in West Germany and more than 50 percent in the Soviet Union." (James M. Beggs)

Robert Cole of the University of Michigan notes that we not only have fewer technical people, but we deploy them in ways that may be adverse to our overall economic competitiveness.

> "...Many of our most talented researchers and engineers have been siphoned off into the defense and aerospace industries...As I visit Japanese companies, I am struck by just how many engineers they have to throw at fairly mundane technical problems...Japanese technical personnel working directly in consumer products industries have been able to generate improvement after improvement, resulting in reduced costs, higher quality and productivity."

Cole also points out that the training and career progression of engineers and technical support personnel in Japan give them a competitive edge. In particular, our nation is weak in the area of technical support people. In Japan, high school graduates are given extensive in-house technical training, allowing them to assume many engineering tasks. This frees up graduate engineers to work on more complex tasks. Our nation's weak-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ness reflects the weak technical background of high school graduates and inadequate training and career path planning in industry. As a result, we are not developing and retaining individuals with the required competencies as well as we should.

Recommendation 8.3 Continue Training Employees for New Technology

Changes in process technology are occurring at an accelerated pace as industries attempt to remain competitive. This means that employees must continually learn new skills in order to keep pace. As one example, Butler observed that the only thing in its disposable diaper line that hasn't changed in the past 20 years is the name of the product! Manufacturing technology has changed and computers have replaced electrical relays for process control. In another area, employees who used to stack paper towel products now program a robot that performs the stacking. Office employees are experiencing changes in technology that are almost as dramatic.

An organization that values its work force and seeks to maintain stable employment must devote considerable time and effort to training.

> "To keep pace with these changing work place demands we must invest 7-10 percent of employees' time in training. That's an investment of up to $3,000 per year per employee in wage dollars alone. Clearly, when we invest that kind of money, we want to make sure we get a proper return. We have to have employees who have the ability to learn and use their training." (Butler)

THEME 9: Improve Quality and Productivity Practices: Building a Quality Ethic

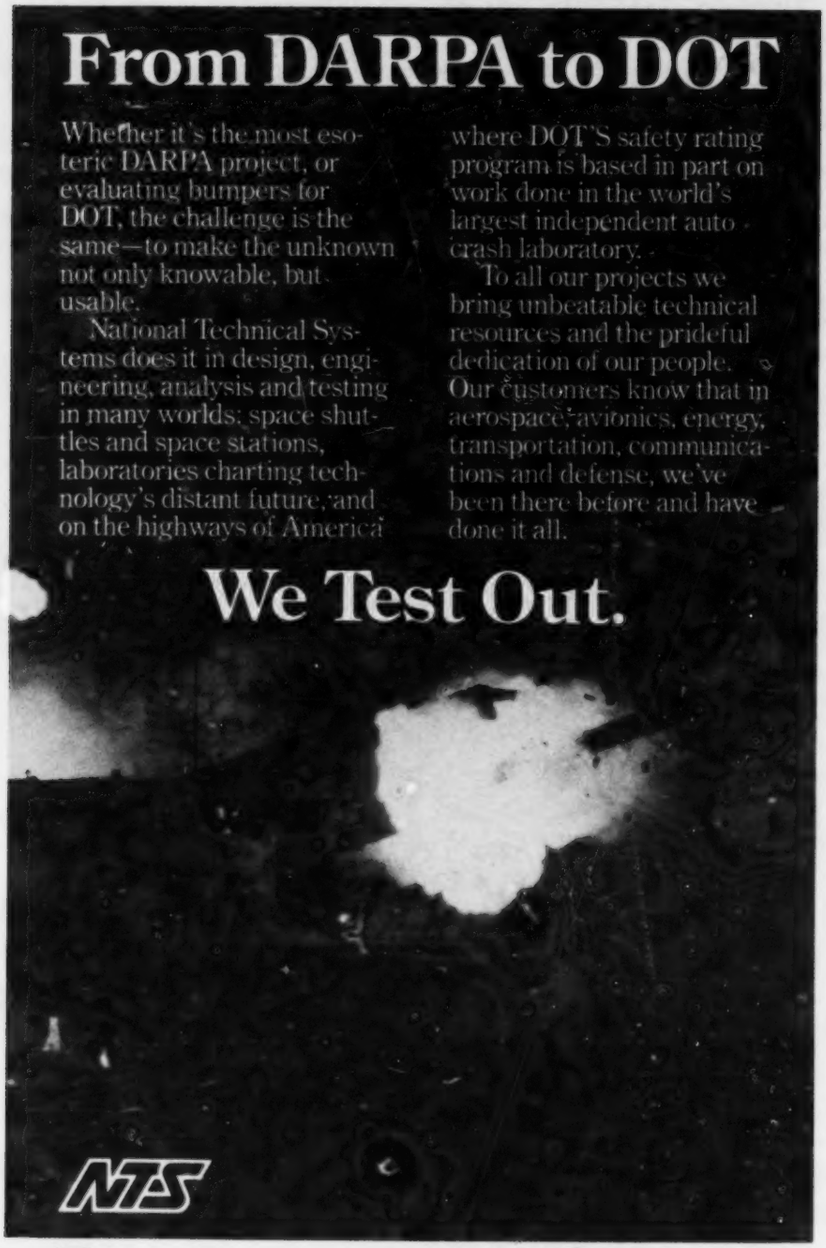
High quality goes hand-in-hand with high productivity. In many organizations, total defect costs range from 15 to 40 percent of budgets. For maximum organizational effectiveness, continuous improvement goals are needed and must have total commitment by management. Every function has customer and quality objectives that have to be translated into specifics that are meaningful to each organizational effort. All levels of management must assess organizational activities and processes on the basis of their impact on quality and productivity—not just on bottom-line results.

> "The whole measure of our success . . . will boil down to quality performance. Shoddy workmanship, defective materials, inadequate quality control, cash overruns—all can be improved or eliminated." (James M. Beggs,)

For industry, the stakes in building a quality ethic are customer satisfaction, cost competitiveness and, ultimately, survival. At IBM, no level of defect is acceptable. John Jackson of IBM states: "More than anything else, quality or excellence stems from the people of an organization . . . and quality is everyone's job . . . Our total quality costs are roughly 15 to 40 percent of the revenue stream." For government, the penalties for failed quality are cost overruns and missed supplier milestones. A quality ethic should permeate every aspect of an organization, starting with hiring the best people and then challenging them to top performance.

> "In contrast to just the traditional emphasis on profits, costs and production goals, leadership has to become obsessed with making sure all decisions are driven by quality improvement, customer satisfaction and building an innovative team environment." (David Braunstein, NASA)

In these comments from his welcoming address to symposium attendees, David Braunstein, Director of NASA Productivity Programs, stressed the underlying mandate to instill the quality ethic in any organization. As such, the pursuit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Circle Reader Action No. 358

of quality and productivity is more an attitude, and not a program goal per se.

Recommendation 9.1 Make Quality a Total Management, Employee and Supplier Commitment

As top management sets organizational goals, so the quality ethic is driven by these goals. Leadership must transcend the narrow perspective of quality in technical terms to one which perceives quality as tantamount to organizational survival. Management must translate quality goals from the abstract, slogan level and relate them to all aspects of employee performance. Quality and productivity are consistently described as different sides of the same coin. This means that employees have to see their jobs not only in terms of "getting the product out" but also in terms of meeting top quality goals. Within an organization this involves how organizational elements cooperate and satisfy each other. Outside the organization it involves the relationship and dealings between customers and suppliers.

> "Our managers, supervisors and foremen are thoroughly educated in the policy that quality is the very life of Sony products. . . They are trained in the field to understand how important quality is for sales and after-sales service." (Sadami Wada, Sony Corporation)

Cooperation between a company and its vendors and suppliers is viewed as a major contributing factor to the high quality levels attained by Japanese manufacturers. Instead of responding to peremptory demands for higher quality, Japanese vendors establish mutually agreed-on targets for improvement as part of a quality plan. This features rapid, two-way feedback for generating suggestions, problem identification and solution, and structuring a system for tracking progress.

The importance of this relationship is the basis of current DoD initiatives described by John Mittino. Since quality has become such a significant issue in the acquisition process, DoD, as the customer, is reemphasizing policies and programs aimed at promoting improved quality practices by contractors.

> "The Department [DoD] encourages commitment from top management and is promoting increased awareness and attention to quality problems during design and manufacturing. DoD is also re-examining its qualification and certification programs to determine whether quality is sufficiently stressed. Perhaps most importantly, we are trying to find new ways to include quality history in our source selection process." (Mittino)

Recommendation 9.2 Incorporate Quality Goals into All Organizational Activities

Quality goals must be understood in terms of the work that an organization performs, the process by which the work is performed and the management system under which the organization is run. As Richard Boyle of Honeywell has stated:

> "When we talk about quality, we're not just talking about products. We're talking about three elements that must be present. . . quality of work, quality of work life and quality of management."

Specific goals must be established for all three elements. Quality of work is what most people mean when they speak of quality. Does the product or service meet the requirements? Is it satisfactory to the customer? This analysis involves all individuals and functions of the organization.

Quality of work life is the degree to which the work environment allows and motivates employees to contribute to the success of the organization. Does the environment offer challenge, responsibility and appropriate rewards? Boyle observes that:

> "Quality of management is the key to sustained quality improvement. It involves fostering leadership that has the technical and intellectual skills to set the course for the organization."

The successful translation of quality goals into an organization's activities begins when employees can answer the question, "What is *my* job?" The job should be defined in terms of both the goods or services produced and the needs of the "customers" who receive them. When employees can answer this question, the organization can then focus on quality goals to increase its effectiveness. Without quality goals and a plan for achieving them in all organizational activities, we cannot develop a process for continual improvement.

> "The more effective approach has been to establish a quality improvement plan. . . The plan usually involves a system for rapid and accurate feedback. . .[so that] suggestions for improvement can be exchanged and progress can be tracked." (Richard Kraft, Matsushita)

Recommendation 9.3 Assess Organizational Activities and Processes As Well As Bottom Line Results

People and processes provide the conditions for quality improvement, which is the driver for productivity. As viewed by Carl Hirsch of Dana Corporation:

> "The pursuit of quality is never finished, because the capacity of our people to produce quality is virtually unlimited. That's why we at Dana will not stop evolving and striving. . . It may be good—but excellence is never really enough."

Management must continually strive to improve the quality of its products, as well as the capabilities of its processes. Responsibility rests with all levels of management to review these processes and determine, through analysis, what they contribute to the bottom line. These reviews must be conducted at key points and be based on facts. Moreover, these reviews should focus on defect prevention.

> "Screening by rejection only increases cost. Therefore, efforts must be made to manufacture right the first time. This is the real quality control. You must be able to obtain the desired level of quality with the least waste." (Wada)

Richard Kraft recommends following the Japanese example of accepting the quality teachings of Dr. W. Edwards Deming, Dr. J.M. Juran and others. The Japanese have accepted the premise that superior quality leads to competitive success, costs little and creates a worldwide demand for goods because of their reputation. □

• • •

NASA's Office of Productivity Programs will host both a conference and a national symposium on quality and productivity in 1986. The Third Annual NASA Contractors Conference will be held at Ames Research Center, Sunnyvale, California, in June 1986. The national symposium, "Strategies for Revitalizing Maturing Organizations," will be held December 2—3, 1986, in Washington, D.C. For more information on these programs, contact David Braunstein, director, NASA Productivity Programs, NASA Headquarters, Code ADA, Washington, D.C. 20546.

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Letters

The "Letters" column is designed to encourage a wide exchange of ideas among *NASA Tech Briefs* readers. To contribute a request for information or to respond to such a request, use the feedback cards in this issue, or write or call: Manager/Technology Transfer Division, P.O. Box 8757, Baltimore/Washington International Airport, MD 21240; (301) 859-5300. While we can print only a small number of letters, we will endeavor to select those that are of varied and wide interest.

TO MAKE A LONG STORY SHORT

As usual I was very pleased to receive the most recent March/April 1986 issue of NASA Tech Briefs. Although at first glance many of the topics may appear to be very narrow in scope, upon more careful scrutiny and with a little imagination, new applications may become apparent.

I would like to set the record straight in regard to the development of using cross-linked EVA material in the cooling garments used on the space shuttle suits [NTB March/April, p. 139]. *It was Johnson Space Center who initially contacted Thermoplastic Processes Inc. in Stirling, New Jersey, pertaining to a problem they were experiencing with plasticizers leaching out into the cooling solutions. At their request, we submitted the first samples of product code 1861 Micro-Line tubing for evaluation. Although this initial sample was less flexible than desired, it proved superior to what they were previously using. We asked NASA how they planned on bonding this rather inert tubing to the then existing flexible PVC fittings. We were told that they would use epoxy. We said, "Good luck."*

A few days later NASA called back and said, "We give up. How are you supposed to bond it?" Thermoplastic Processes Inc. suggested that heat fusing be looked into. We then supplied NASA with samples of telescopic sizes of our cross-linked Bev-A-Line VHT tubing for the initial heat fusion tests, and made an offer that if NASA were to supply samples of the EVA fittings to us we would cross-link them through irradiation so that the dimensional stability of the various components would allow them to be heat fused together with minimum distortion! Eventually we supplied softer versions of cross-linked EVA for even more flexibility.

There is no doubt that the very talented and dedicated people at ILC Dover sophisticated this technique to a new standard of excellence. However, I believe it is only fair for my employer, Thermoplastic Processes Inc., to receive their due credit.

Joseph Rene DuPont
Gillette, NJ

MORE Q's & A's

What do we do if we are interested in tech briefs marked "No further documentation is available"?

D.W. Hejde
Washington, DC

When no Technical Support Package (TSP) is available for a particular tech brief, or if you have further questions about applying the technology described in a TSP, you should contact the Technology Utilization Officer at the NASA Field Center that sponsored the research. He can put you in touch with the individuals who conducted the R&D that led to the innovation. The names, addresses, and phone number of NASA's Technology Utilization Officers are listed on page 29 of this issue.

Do you publish an annual list of all NASA Tech Brief entries?

Indices for Tech Briefs published prior to 1980 are available from the National Scientific and Technical Information Facility, Technology Utilization Office, P.O. Box 8757, Baltimore/Washington Int'l. Airport, MD 21240. We regret that no indices are currently available for Tech Briefs published after 1980. Publication of these indices is expected in the near future and will be announced in NASA Tech Briefs.

How do I go about getting information on the price and availability of the NASA Patent Abstract Bibliography (PAB)?

The NASA Patent Abstract Bibliography, containing abstracts of all NASA inventions, can be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161. The PAB is updated semi-annually. NTIS furnishes the PAB to subscribers who place a standing order by opening a deposit account in the amount of $25. The price of each PAB is then charged against this amount.

For more information, write NTIS at the above address or phone (703) 487-4630.

POETRY IN MOTION

After I had already finished making the improvements for the GM auto washer pump, the schematic for fluidic devices published in NASA Tech Briefs was brought to my attention. From the knowledge gained, I was able to develop a simple, non-mechanical device costing 15 cents to 25 cents, as against the GM washer pump's $18.00 to $20.00 manufacturing cost.

More importantly, the bending of a fluid stream in a horizontal plane is clearly observable in this device. This phenomenon may be likened to "light from a distant star bent by a curve in space-time caused by the mass of the sun" (Einstein).

John Izumi
Izumi Co.
Glen Ellyn, IL

QUALITY & PRODUCTIVITY

Your articles on "Improving Quality and Productivity in Government and Industry" were magnificent! Best stuff I have read in many years. As a government employee with 17 years invested in the system, I can tell you that everything said about stifling creativity was right on the money. Every day the government kills 1000 good ideas with the same weapon Sampson used to slay the Philistines!!

John R. Jay
Pacific Missile Test Center
Point Mugu, CA

Please let me know how to get a copy of the recommendations of the 1984 Symposium on Quality and Productivity, referred to on page 182 of the Winter 1985 issue of NASA Tech Briefs. Looks like a very interesting item.

G.M. Clark
CIBA-GEIGY Corp.
McIntosh, AL

With this issue, NASA Tech Briefs concludes its presentation of the themes and recommendations of the 1984 Symposium on Quality and Productivity by reprinting themes 7-9, beginning on page 157. Themes 1-3 were reprinted in the Fall 1985 issue of NTB, and themes 4-6 can be found in the Winter 1985 issue. NASA Tech Briefs chose to reprint these findings not only because we thought our readers would find them informative, but also because only a limited number of reports were available from NASA's Office of Productivity Programs, which sponsored the 1984 symposium.

NASA's Office of Productivity Programs will host another national symposium on quality and productivity in 1986. For more information on this program, contact David Braunstein, director, NASA Productivity Programs, NASA Headquarters, Code ADA, Washington, DC 20546.

GETTING THE BIG PICTURE

NASA Tech Briefs articles present not merely design techniques but an important way of thinking about systems which ought to be understood by project engineering teams. The presented techniques light the highest levels of systems conceptualization down to the lowest level of product design. The articles, though very brief, often help to change the conceptual thinking, while at the same time providing a directory to important engineering information.

Julian J. Dec
Comstock Engineering, Inc.
Butler, PA

In our organization, it is necessary for proposals for new contracts to keep current with all new aerospace developments that can impact how we design and produce new products. NASA Tech Briefs has been very useful to us in doing this.

Ralph I. Olsen
Boeing Aerospace
Seattle, WA

I am a mechanical engineer who's been reading Tech Briefs for many years. I'm keenly interested in the content of this magazine overall, because of the added knowledge and insight it gives me. I have an insatiable interest in unique solutions to design engineering problems. Tech Briefs, more than any other publication, has piqued that interest consistently.

Keith Whaley
Hughes Aircraft
Los Angeles, CA

I like the ads! Not only do they offset the cost of producing NASA Tech Briefs, but they let high-tech companies know about other high-tech companies.

Keep up the good work. NASA is the only branch of the federal government I would like to pay more taxes to support!

Douglas C. Smith
AT&T Information Systems
Middletown, NJ

SONS AND MOTHERS

Our company is primarily involved with computer simulation and technical analysis. I hope that we will be able to learn much more from Tech Briefs. My mother, who receives Tech Briefs, has always loved your publication and has been able to use what she has learned from your publication.

Richard V. Rudofski
Jaycor
Fairborn, OH

CORRECTION

The following equation for correcting nonlinearity in a photodetector appeared incorrectly on page 48 of the March/April issue of NASA Tech Briefs. In its proper form, the equation is:

$$R_3 = \frac{R_f R_1 R_2}{R_s R_b}\left(\frac{R_s + R_b}{R_1 + R_2}\right)$$

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Subject Index

This document was prepared under the sponsorship of the National Aeronautics and Space Administration. NASA Tech Briefs is published bi-monthly and is free to engineers in U.S. industry and to other domestic technology transfer agents. It is both a current-awareness medium and a problem-solving tool. Potential products...industrial processes...basic and applied research...shop and lab techniques...computer software...new sources of technical data...concepts...can be found here. The short section on New Product Ideas highlights a few of the potential new products contained in this issue. The remainder of the volume is organized by technical category to help you quickly review new developments in your areas of interest. Finally, a subject index makes each issue a convenient reference file.

Further Information on innovations—Although some new technology announcements are complete in themselves, most are backed up by Technical Support Packages (TSP's). TSP's are available without charge and may be ordered by simply completing a TSP Request Card, found at the back of this volume. Further information on some innovations is available for a nominal fee from other sources, as indicated. In addition, Technology Utilization Officers at NASA Field Centers will often be able to lend necessary guidance and assistance.

Patent Licenses—Patents have been issued to NASA on some of the inventions described, and patent applications have been submitted on others. Each announcement indicates patent status and availability of patent licenses if applicable.

Other Technology Utilization Services—To assist engineers, industrial researchers, business executives, Government officials, and other potential users in applying space technology to their problems, NASA sponsors Industrial Applications Centers. Their services are described on pages 28-29. In addition, an extensive library of computer programs is available through COSMIC, the Technology Utilization Program's outlet for NASA-developed software. See special section on computer programs on page 74.

Applications Program—NASA conducts applications engineering projects to help solve public-sector problems in such areas as safety, health, transportation, and environmental protection. Two applications teams, staffed by profesionals from a variety of disciplines, assist in this effort by working with Federal agencies and health organizations to identify critical problems amenable to solution by the application of existing NASA technology.

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Mission Accomplished

Through the technology transfer process, many of the systems, methods and products pioneered by NASA are re-applied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.

This nuclear magnetic resonance (NMR) image of the human brain was enhanced using NASA remote sensing technology. The image describes a tumor on the left lobe (the yellow mass on the right side of the image). The opposite lobe is normal except for some swelling (also in yellow), which appears around the cerebral spinal fluid cavity (shown in red).

For many of us, the subject of remote sensing is remote indeed. We tend to think of complex satellite and radar systems, and in doing so we forget that mechanisms as common as the camera are designed for the same purpose: to gather information about an object without coming into physical contact with it.

In the medical world, the x-ray machine is probably the most widely-used remote sensing instrument. It gathers information about the body based on its sensitivity to bone density. X-rays, however, are limited by their inability to penetrate bone, and thus are inadequate when images of soft tissues are required.

To obtain images of soft tissues, especially the brain, a relatively new technique called nuclear magnetic resonance (NMR) imaging has been developed. NMR data is gathered by measuring the energy the body's hydrogen protons release after the temporary imposition of an electromagnetic field. Then, with the help of a computer, this data is converted into images that, like x-rays, are useful in medical diagnostics.

While the technology for generating NMR data is relatively advanced, NMR data processing and analysis systems are not yet fully developed. Consequently, NMR images tend to lack definition, which makes them difficult to interpret. But recently the NMR data processing system has been greatly improved. Reformating NMR data to make it compatible with NASA remote sensing software has dramatically enhanced the clarity and consistency of NMR images, making them much more useful in medical diagnostics.

To process and analyze the digital data provided by its remote sensors, scientists at NASA's National Space Technology Laboratories, Bay St. Louis, Mississippi, developed the Earth Resources Laboratory Applications Software (ELAS). This conglomeration of 300 separate executable programs analyzes satellite and other remotely gathered data and converts it into colorful and highly detailed images.

In much the same way that NASA scientists use computer-enhanced images to assess the status of earth resources, medical diagnosticians use NMR images to detect anomalies, such as blood clots and tumors, in soft tissues. Enhancing NMR imaging technology is the goal of a three-year collaborative effort between doctors at the Mallinckrodt Institute of Radiology of the Washington University Medical Center, St. Louis, Missouri, and NASA scientists. Kennedy Space Center is providing funding and overall coordination for the project, while Washington University is supplying medical expertise and data. NSTL scientists are providing analytical capabilities based on the ELAS software and the expertise they've acquired through years of image processing and analysis.

One of the preliminary tasks of the NSTL scientists was to eliminate the systematic errors and high-frequency noise contained in the NMR data. This was partially accomplished by determining the necessary correction factors with the ELAS software. Then, using the computer, they enhanced the typically black and white NMR images by assigning color values to the digital data. Current efforts focus on further enhancing the color images to the point where they provide information on the biological behavior of a soft tissue anomaly, in addition to determining its size and location. This enhancement will allow diagnosticians to non-surgically differentiate blood clots from tumors, and further, determine whether a tumor is benign or malignant.

By using NASA software and analytical expertise to maximize the interpretability of NMR images, the rate of soft tissue disease detection will be greatly enhanced. From there it follows that treatment can be started earlier, hopefully in time to alter the course of life-threatening disease. □

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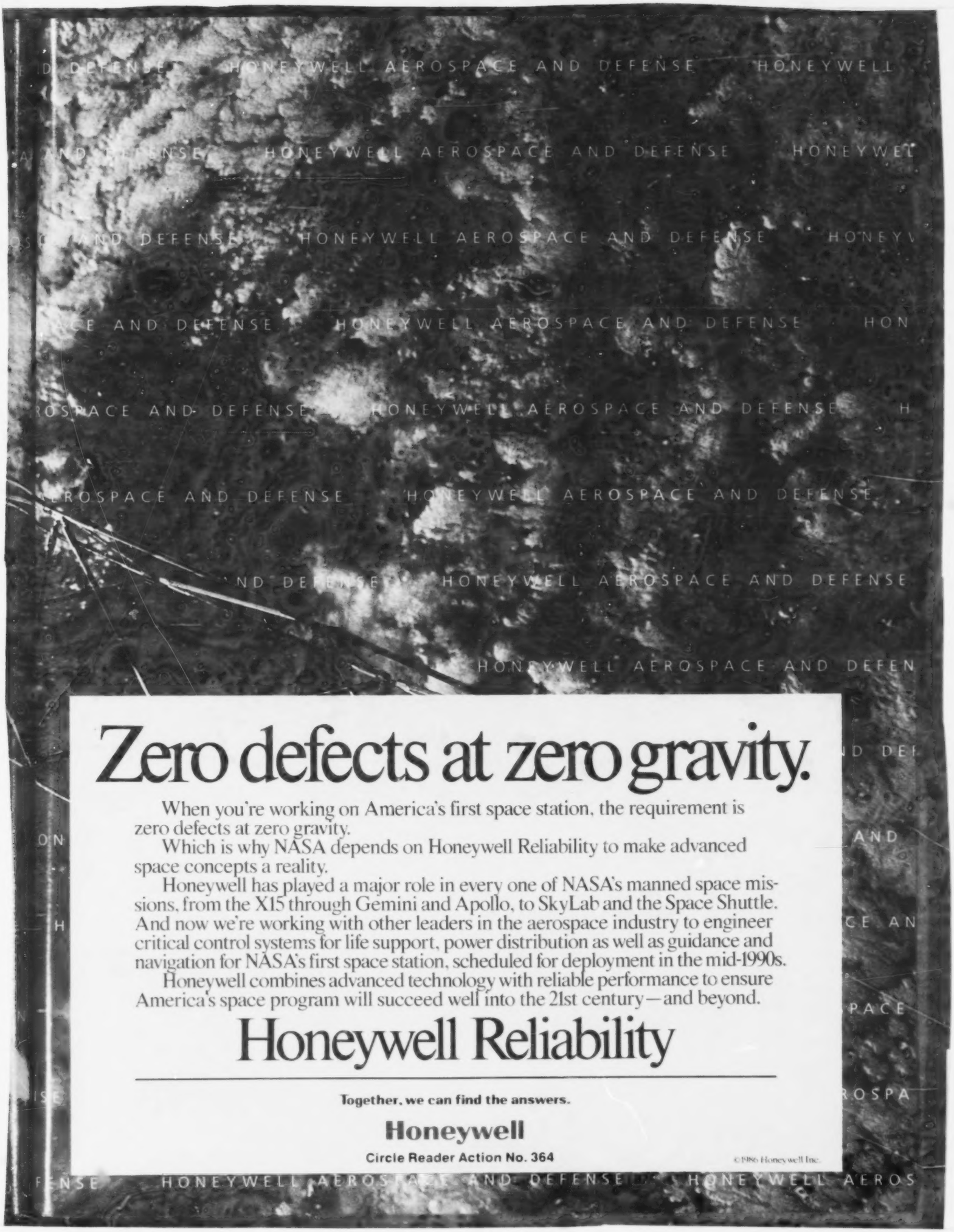

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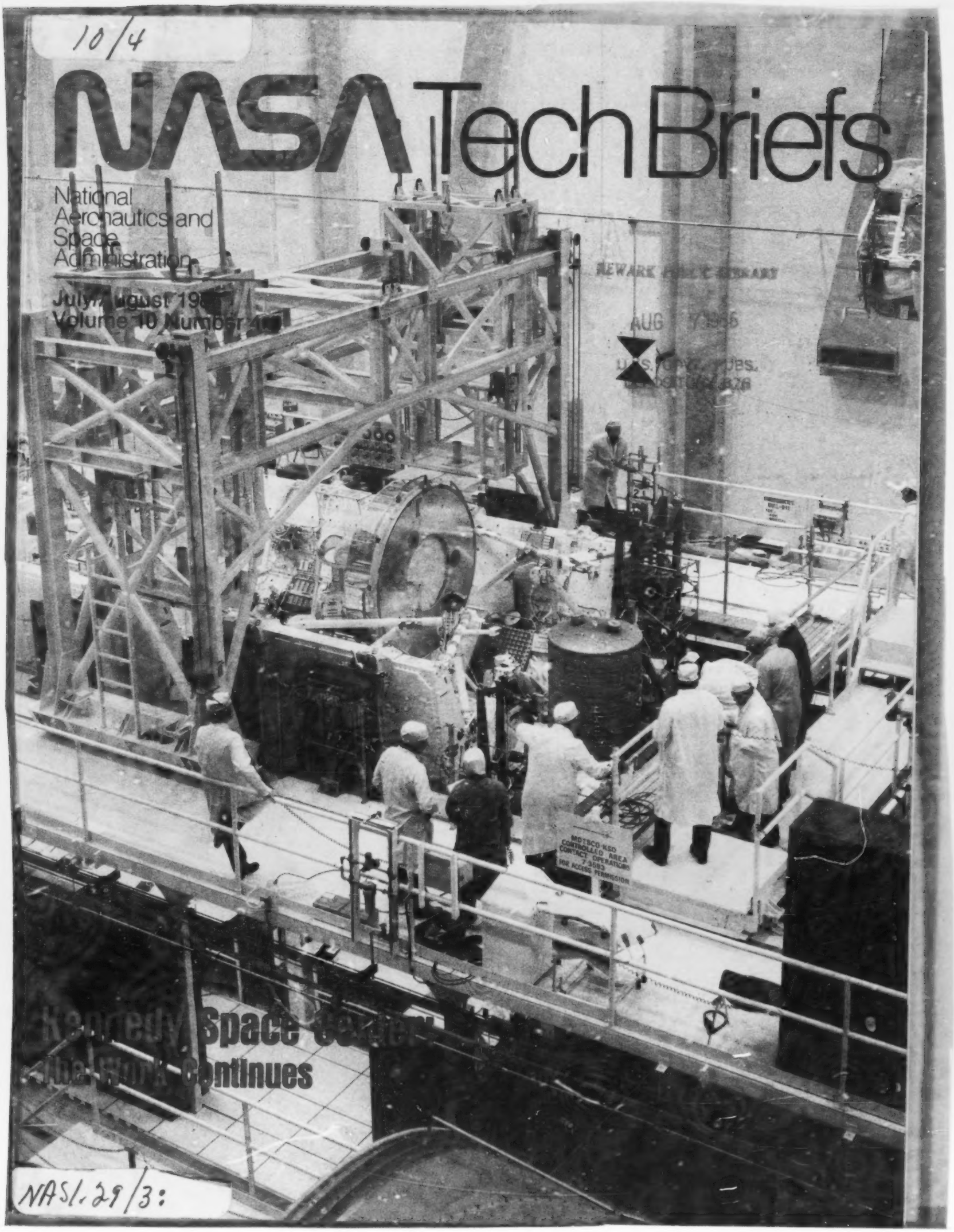
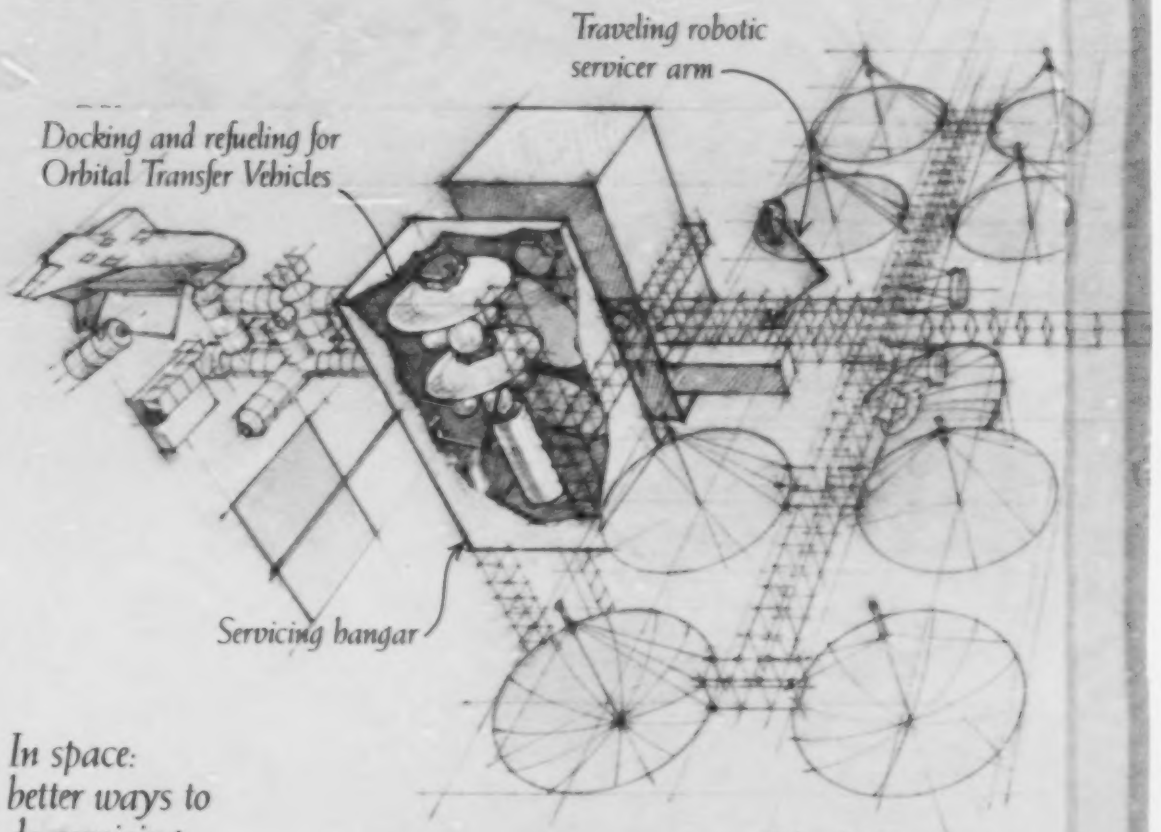


Kennedy Space Center: The Work Continues

NASI.29/3:

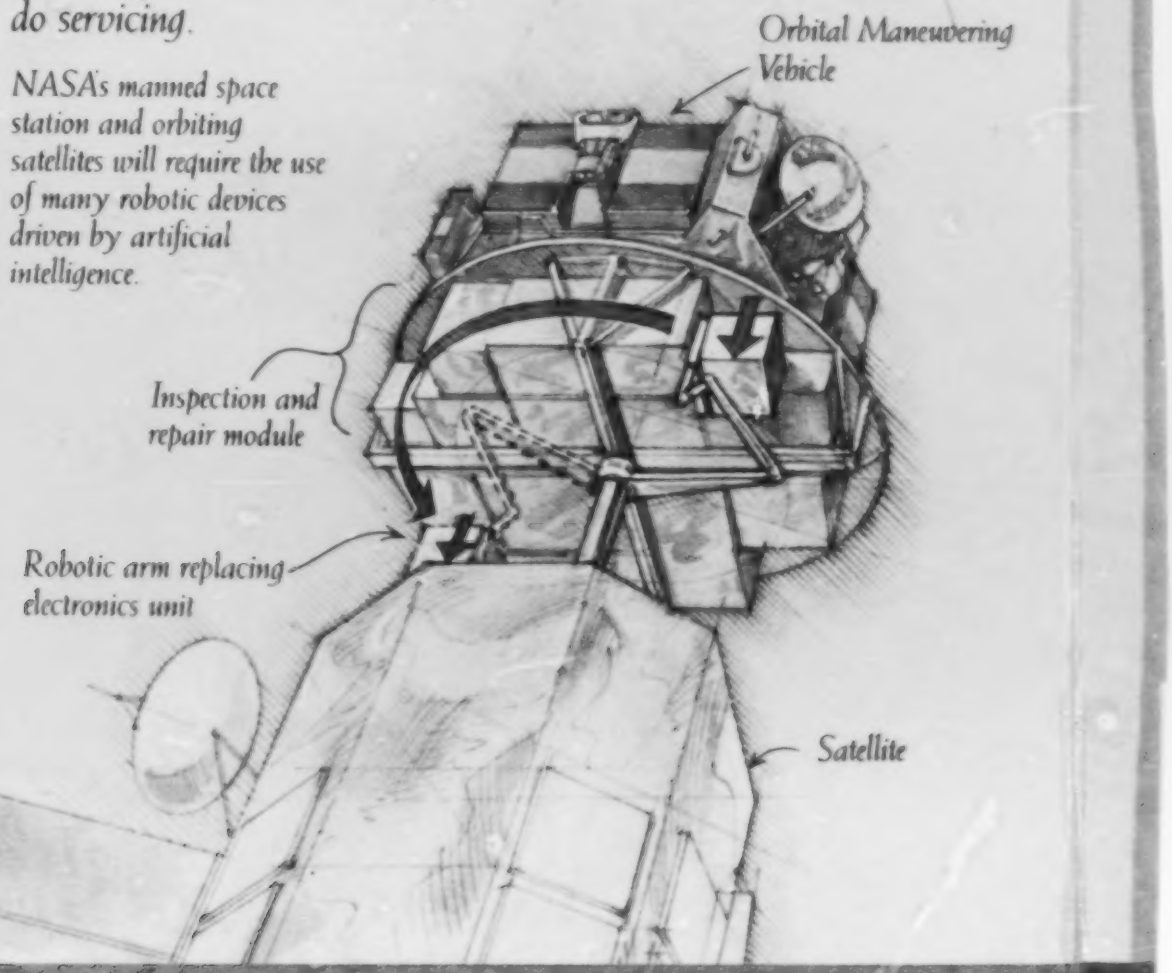
Artificial intelligence and robotics: giving machines the ability to sense, reason and act.

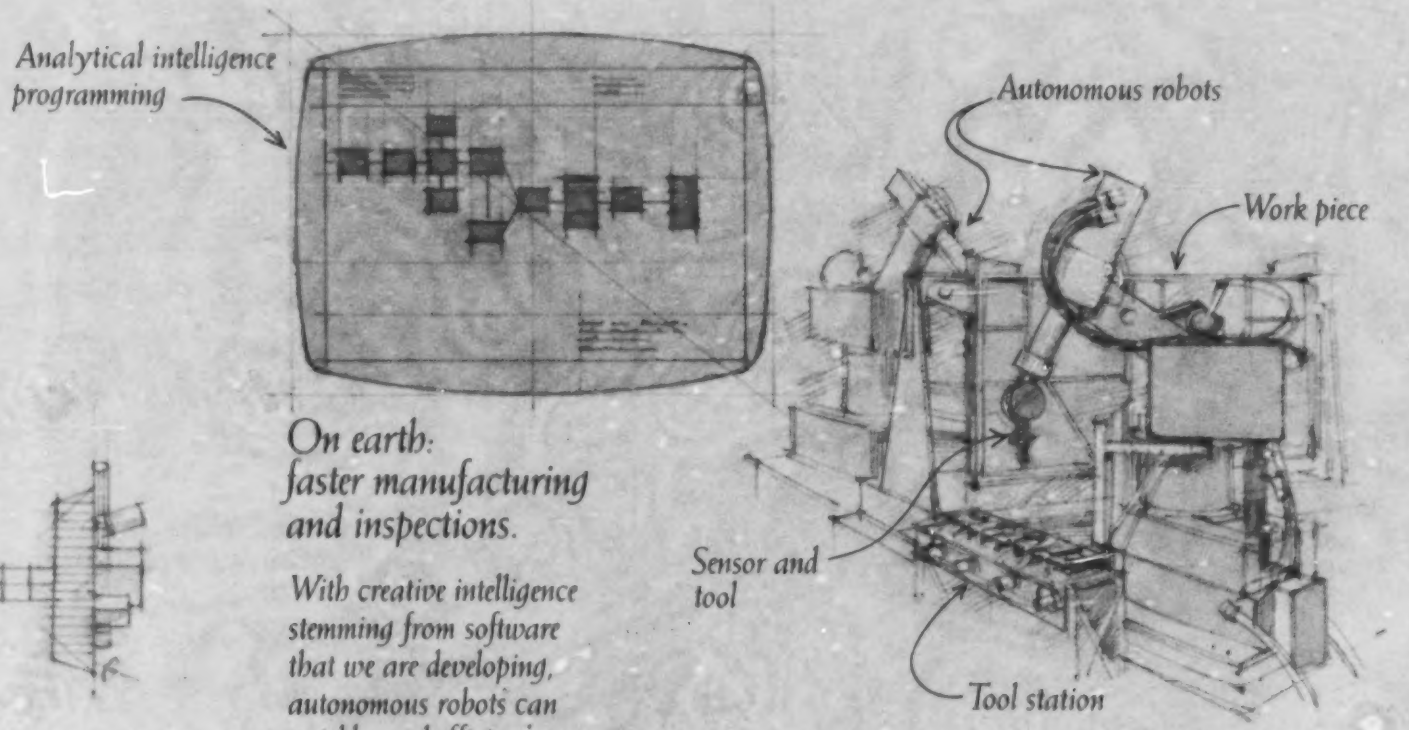
Much as it may hurt to think so, many things might be done better by independently functioning machines than by humans. Certain tasks may require superhuman precision or speed, or need to be done where humans can't go. Martin Marietta is creating systems that combine the ability to sense, reason and take action—to function autonomously and intelligently. And we are exploring ways to put them to work on a variety of tasks.



In space: better ways to do servicing.

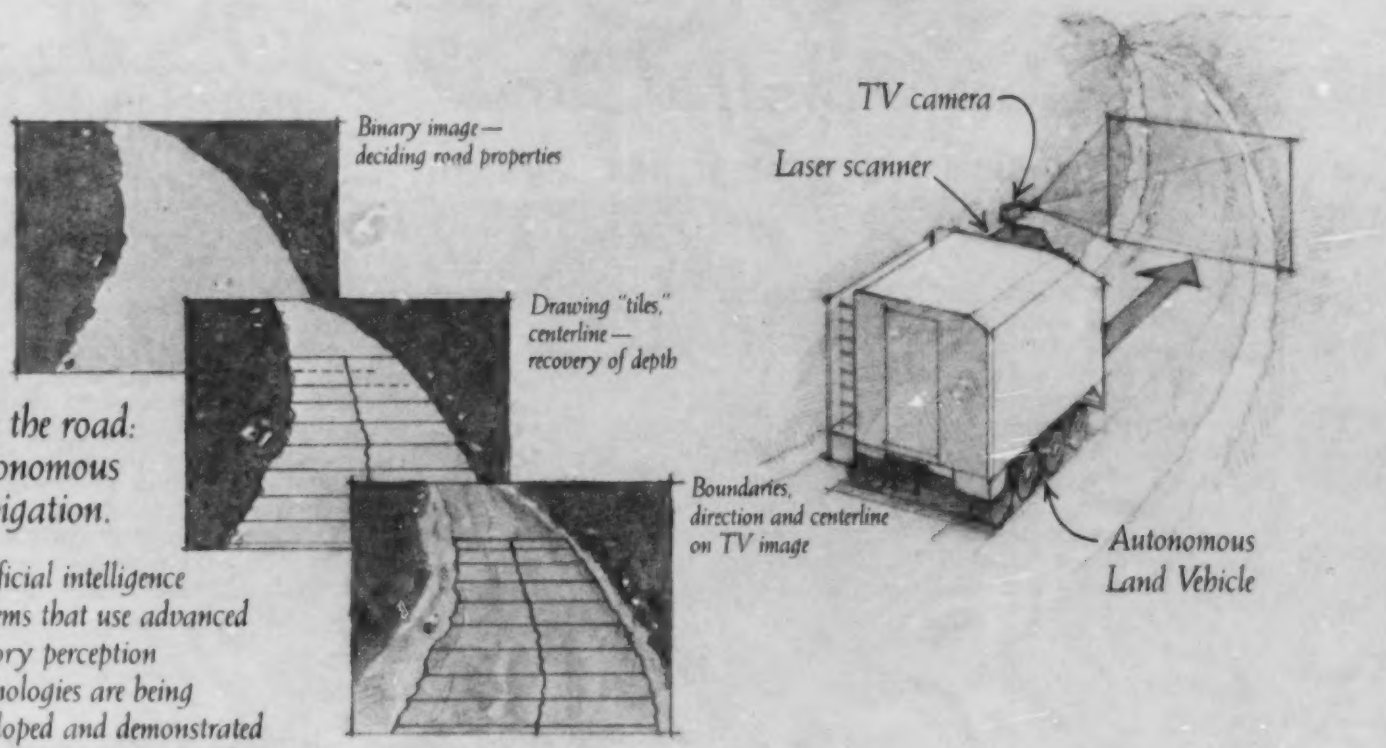
NASA's manned space station and orbiting satellites will require the use of many robotic devices driven by artificial intelligence.





On earth: faster manufacturing and inspections.

With creative intelligence stemming from software that we are developing, autonomous robots can quickly and efficiently perform batch manufacturing and precision inspections, even choose their own tools.


Binary image— deciding road properties
Drawing "tiles," centerline— recovery of depth
Boundaries, direction and centerline on TV image
TV camera
Laser scanner
Autonomous Land Vehicle

On the road: autonomous navigation.

Artificial intelligence systems that use advanced sensory perception technologies are being developed and demonstrated in the Autonomous Land Vehicle. Already able to follow roads, this mobile test bed will eventually be able to plan its route, avoid obstacles and even thread its way across country.

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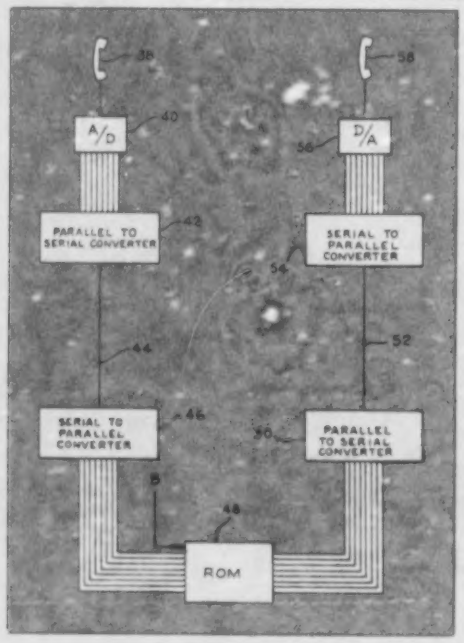

A newly patented telephone conference calling system is one of NASA's latest inventions . . .page 149.

In addition to being the nation's spaceport, Kennedy Space Center is part of a national wildlife refuge—home to this blue heron . . .page 12.

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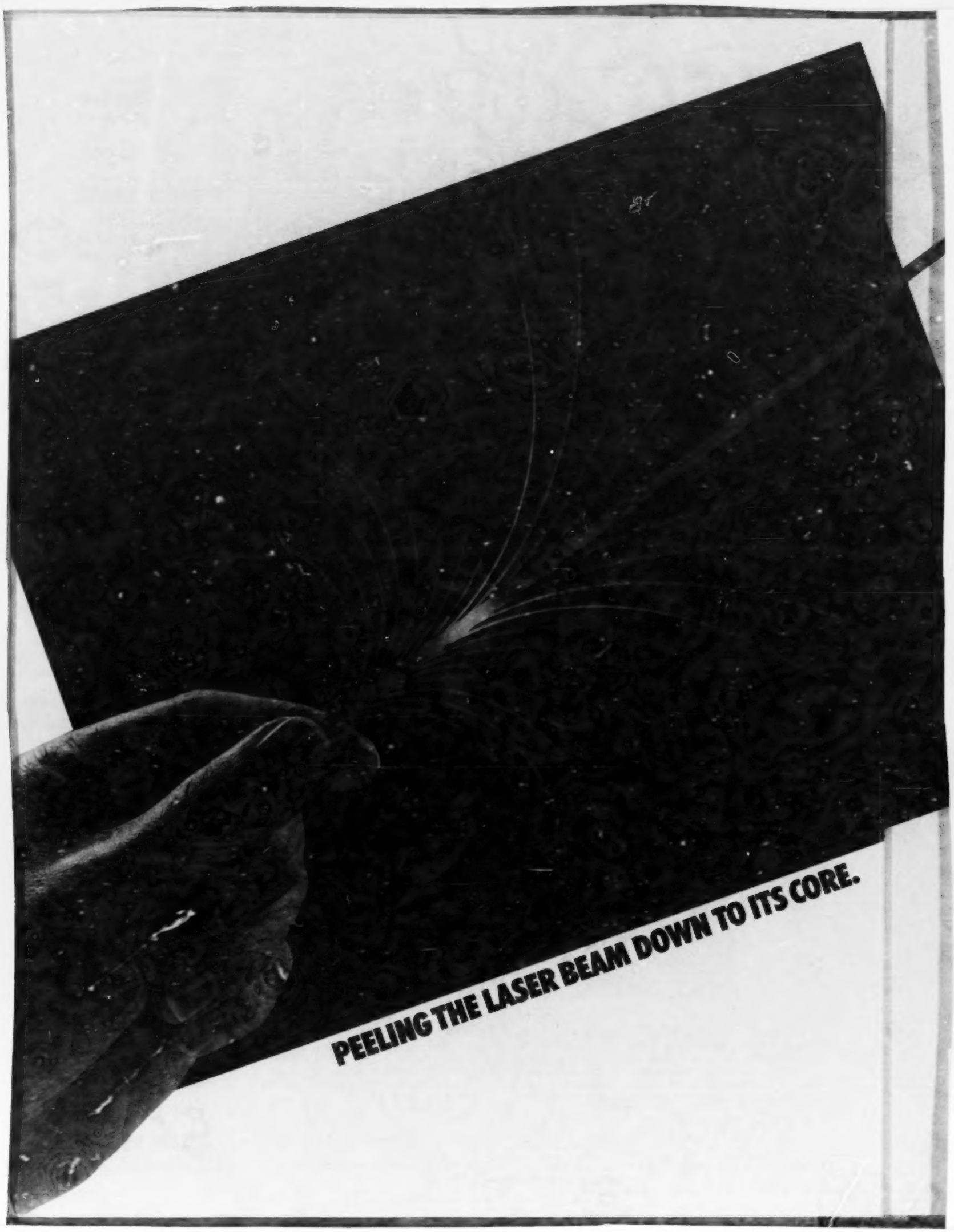

PEELING THE LASER BEAM DOWN TO ITS CORE.

AT&T Bell Laboratories scientists have generated a beam from a diode laser with a frequency spectrum 1,000,000 times narrower than that of today's most advanced commercial semiconductor lasers.

Part of a record-breaking coherent lightwave system, this laser 'peels away' a tremendous number of unwanted frequencies that can clutter up a beam—to create a lightwave so pure, its frequency variance is limited to 1 part in 40 billion. The equivalent of one drop of ink in a million-gallon, Olympic-size swimming pool.

A drop in 40,000,000,000

Purity Has Its Rewards

The new narrow-spectrum laser is the key element in a coherent lightwave communications system that increases the information-carrying capacity of an optical fiber, as well as the distance over which an unboosted laser beam can be received.

Increased capacity comes from dramatically increasing the number of individual laser beams that can be sent through a fiber's best transmission window.

Each laser in a coherent system produces an exceptionally stable, pure wavelength—allowing thousands of non-interfering wavelengths to travel side-by-side on a fiber. (Only a handful of beams can be combined using today's commercial semiconductor lasers.)

Dial 'M' For Movie

In the future, the capacity of coherent transmission could allow us to send 10 million conversations—or 10 thousand digital TV channels—simultaneously, on a single fiber.

Or, using the full capacity of a fiber, a coherent system could dump a movie like 'Gone with the Wind' into a home memory unit in one second flat. Or deliver Beethoven's '5th' in less than a 50th of a second.

Making A Little Go A Longer Way

Increasing capacity is important in an age of rapidly expanding information needs. But so is reducing costs—in this case, by nearly doubling the distance an unboosted signal can be received.

A newly developed AT&T coherent lightwave receiver contains its own narrow-spectrum laser. The beam from this laser reinforces the transmitted signal as it detects it—a technique only possible with two such pure beams.

Using this receiver, AT&T has achieved a laboratory transmission record of nearly 100 miles at a data rate of 1 billion pulses per second.

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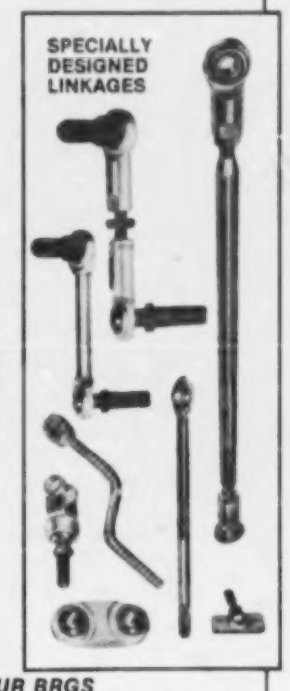

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Apollo Soyuz 1975
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in Space Station development.

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RCA
Aerospace and Defense Communication and Information Systems

Editorial Notebook

Once Upon A Time In A Land Far Away . . .

It's dollars to doughnuts that if Gutenberg had invented the printing press a couple of centuries earlier, there'd have been a *Palos Post* or a *Barcelona Times* editorial questioning Queen Isabella's sanity. I can see it now.

Is This Trip Necessary?

BARCELONA, April 30, 1492—Racked with a deficit left over from the Crusades, plus the heavy burden the recently completed Moorish wars have placed upon the treasury, our Good Queen Isabella has seen fit to underwrite the peregrinations of an itinerant Genoan boat bum who can't even get the support of his own government.

Why? To find a new route to the Indies . . . a place we can reach perfectly well by land! First, he's an odds-on favorite to fall off the edge of the earth. Second, even if he doesn't fall off, it doesn't mean we're going to discover any new routes. Third, there are far more pressing projects. We've got an Inquisition to fund. Our fight with the Moors won't be finished until every last one has been converted.

Moreover, national defense is paramount. Our enemies hound our flanks . . . and one of them will probably capture Columbus's entire expedition anyway.

We would be better off increasing our subsidy of the Flat Earth Society and leaving the trailblazing to the Dutch, or any other nation foolish enough to pursue it. If The Throne feels it must pursue the matter, it should send unmanned craft on such a dangerous expedition.

Not Again!

PALOS, March 15, 1493—Crepuscular Chris is back, with the Santa Maria wrecked and the Nina badly damaged. Just as we predicted, no benefits. His new route to the Indies ends up in an uncivilized area of the boondocks which is inhabited by naked savages to whom the wheel is big news. Their mechanical ability is exceeded only by their artistic expression, which seems to consist of painting their bodies with mud before eating each other. And they smell just as good as you'd expect.

And he has the gall to want 17 more ships to go on another expedition? Columbus's ventures are a hole in the water into which our Good Queen is determined to throw money. It is high time Ferdinand brought her to her senses and determined a sensible policy for Spanish exploration. The monarchy should assign the Navy a goal that justifies risking lives at sea. Resuming the old policy is not the way to learn from the Nina and Santa Maria disasters. The loss of these ships is the right occasion to free the Navy from its aimlessness and at long last give its engineers another project worthy of its skill . . . an Armada, for example.

Columbus Mismanagement Mounts Into Millions

SANTANDER, January 12, 1499—Columbus, his contractors, and staff (some of whom are his family) have wasted millions of Spanish doubloons on the Indian expeditions, despite warning after warning from Empire courtiers that these losses were occurring through bad management. Not only was the entire first settlement wiped out by Indians, but the current Hispaniola settlement seethes with discontent because of poor food, poor living conditions, and inept native labor that produces far less gold than Columbus had promised. It is obvious that his vainglorious project will never be commercially viable.

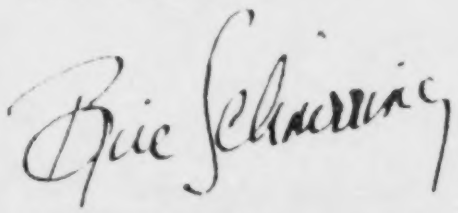
Experts inside and outside the Empire say such faulty administration procedures have severely hurt the Spanish exploration program. The Admiral of the Mosquitos has brought the Empire only the discovery of lands of vanity and delusion which have been the ruin of many a Spanish gentleman. It is at least heartening to know that Bobadilla is investigating the whole mess and has sent Cornucopia Chris and his brothers back to Spain in chains for a full accounting.

• • •

The news media's job is to jump quickly on the news and report it. Disaster and blame sell a lot more papers and television time than the technological breakthroughs that enhance our daily lives, though the latter outnumber the former exponentially. We can't change that, but we can remind the media and our elected representatives of the benefits we all have derived and will continue to derive from the space exploration process.

We estimate that we have received about 8,000 feedback cards since we privatized *Tech Briefs*. I've read almost all of them, and they are a spur and a delight. Your positive reinforcement makes us all proud, and your suggestions spur us to improve what you have overwhelmingly affirmed is already an excellent product. In all the thousands of comments I have read, I don't remember a dozen that were really negative. Many of you have said that what we're doing should be more widely known. We're trying to make sure that happens; we've increased circulation over 50% in the past 18 months, and we're growing every day.*

The news media and Congress have been eager enough to point out everything that's wrong with NASA. Your comments show that you know well the work NASA has done and continues to do right. Keep the comments coming to us, but more importantly, share them with your local media and your elected representatives. Your input is important. □



* Look for a bonus this year . . . an extra issue. NTB's *Computer Preview '87* will look at NASA's software and hardware at headquarters, at each of the field centers, and at COSMIC.

Product/Research Developments®

Fourth of a series

General

This series of advertisements is presented in the interest of providing information that may help you do your job for the U.S. Government better and more economically.

Today, with *budget-cutting* a common objective, we would like to highlight a few of the newer breakthroughs in 3M's line of more than 40,000 products that might be especially effective in helping you realize significant savings in your operations.

Moreover, the Federal Systems Department/3M stands ready to help you expedite procurement.

A silver lining

A special 3M silver film has been developed with a capacity for *95% specular reflectivity* — the highest reflectivity of any material currently available.

This "silver lining" is the secret of *Silverlux*™ Fluorescent Reflectors, which can be installed easily in existing fluorescent fixtures. Because of their remarkable reflectivity they allow optimum lighting with as few as *half* the normal number of fluorescent lamps.

With the cost of office lighting running 40% to 60% of the average office energy budget, half the number of lamps, half the ballasts, and half the energy consumption mean big savings.

In addition, where air conditioning accounts for significant energy usage, the reduced lighting wattage with *Silverlux* Fluorescent Reflectors means less heat and correspondingly lower air conditioning requirements.

Storage savings

3M optical media make possible economies on a scale unimaginable only a few years ago.

For example, a 1.2 gigabyte *3M* Optical Disk stores as much information as *thousands* of five-and-a-quarter-inch floppy disks. That's 1,200,000,000 bytes.

This high packing density means not only big savings in storage space, but also even bigger savings in retrieval time, since time spent searching out and inserting disks is cut by factors in the hundreds and thousands.

3M has developed several types of optical disk for industrial audio, video, and data storage and retrieval. *Read-Only Discs* (*3M* "CD-ROM", or new *3M* "OROM" for high-performance computer applications) are for mass replication of large data bases and software packages. *Write-Once Optical Disks* are user-recordable, and provide for storage of permanent documents such as medical, military, and law-enforcement records.

And among our latest breakthroughs, *3M Erasable Optical Disks* use a laser to read, write, erase, and write again.

These versatile disks store large amounts of data, and also let you change and update information quickly, easily, and economically.

3M engineers will be pleased to work with you directly to develop any special application you may envision for the exciting new technology of the optical disk.

Cut costs two ways

Surprising as it may seem, *one* 3M product can cut *both* your heating *and* your air conditioning bills.

Through a patented 3M technology, *Scotchtint™ Plus* Window Film cuts heat loss through windows by 20% to 48%, and also rejects 60% to 77% of the sun's intense heat — before it even enters your building.

On average, for every 100 square feet of sun-lit glass covered with *Scotchtint Plus* Window Film you can save *one ton* of air conditioning.

And your people feel cooler in summer, warmer in winter (even next to windows), and are protected from glare — factors likely to significantly improve their productivity.

Durable and attractive, *Scotchtint Plus* Window Film is available in a variety of densities and colors.
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Conclusion

3M is a pioneer and world leader in a wide range of disciplines and technologies.

From photographic film to magnetic tape to optical media.

And expert in the fields of precision coatings, optics, polymer chemistry, and adhesives.

If you need to reduce costs and improve productivity, 3M may have a solution for you.

For more information just call 800-328-1684 toll free (or 800-792-1072 in Minnesota). Descriptive literature will be mailed to you without cost or obligation. Or if you wish, a 3M representative will call you for an appointment at your convenience.

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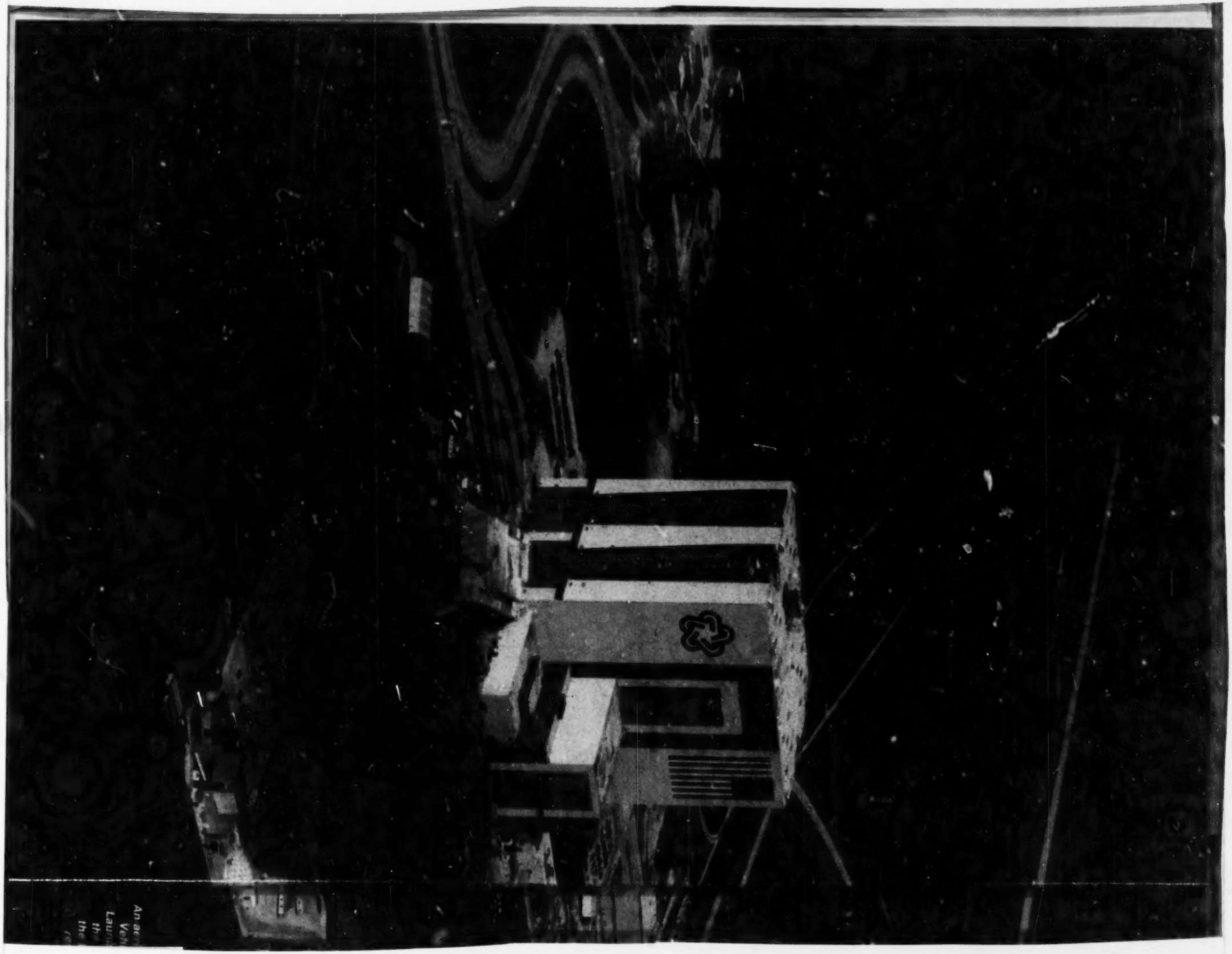

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An aerial view of Kennedy Space Center shows the 525-ft. tall Vehicle Assembly Building. Adjacent to it on the left is the Launch Control Center. The Orbiter Processing Facility is on the right and the three-mile long shuttle landing strip is in the background. At extreme left, a Mobile Launch Platform rests atop a crawler-transporter. Above right: The orbiter Columbia undergoes modification.

Kennedy Space Center:

Gateway to the Last Frontier

In the Orbiter Processing Facility at Kennedy Space Center, teams of technicians move briskly up and down stairs and across walkways. A PA system crackles in the background, and overhead the orbiter Columbia rests in the high bay, her sweeping dimensions obscured by support structures and equipment housings. Minus her main engines, nose cone, elevons and assorted other components, Columbia looks strangely vulnerable—not at all the paragon of 20th-century aerospace technology. For an instant one glimpses the irreducible simplicity of the flying machine, an image quickly swept away by the awesome sophistication of the totality. Up close, the shuttle is a technological proof that the whole is greater than the sum of its parts.

The atmosphere in the Orbiter Processing Facility is charged. Technicians, some of them clad in lint-free caps, coveralls and booties—"bunny suits" in the vernacular—attend to the maintenance and modification needs of the premiere orbiter. Columbia's wings are being reinforced and strengthened, "beefed up" so that the next time she flies, she'll be capable of carrying heavier payloads. Her delicate electronic systems are inspected and tested, again in preparation for her next spaceflight.

It's a far cry from business as usual, but it's business nonetheless at the John F. Kennedy Space Center. The next shuttle launch may be at least a year away, but there's work to be done and schedules to be met just the same. ►

Kennedy

Establishing Capabilities

Launching space vehicles has been the focus of activity on Cape Canaveral for over 35 years. Beginning with captured German V-2 rockets in the early 1950s, the launch litany progresses through Redstone, Thor, Atlas, Scout, Centaur, Jupiter, Delta, Titan and Saturn rockets, culminating with the space shuttle.

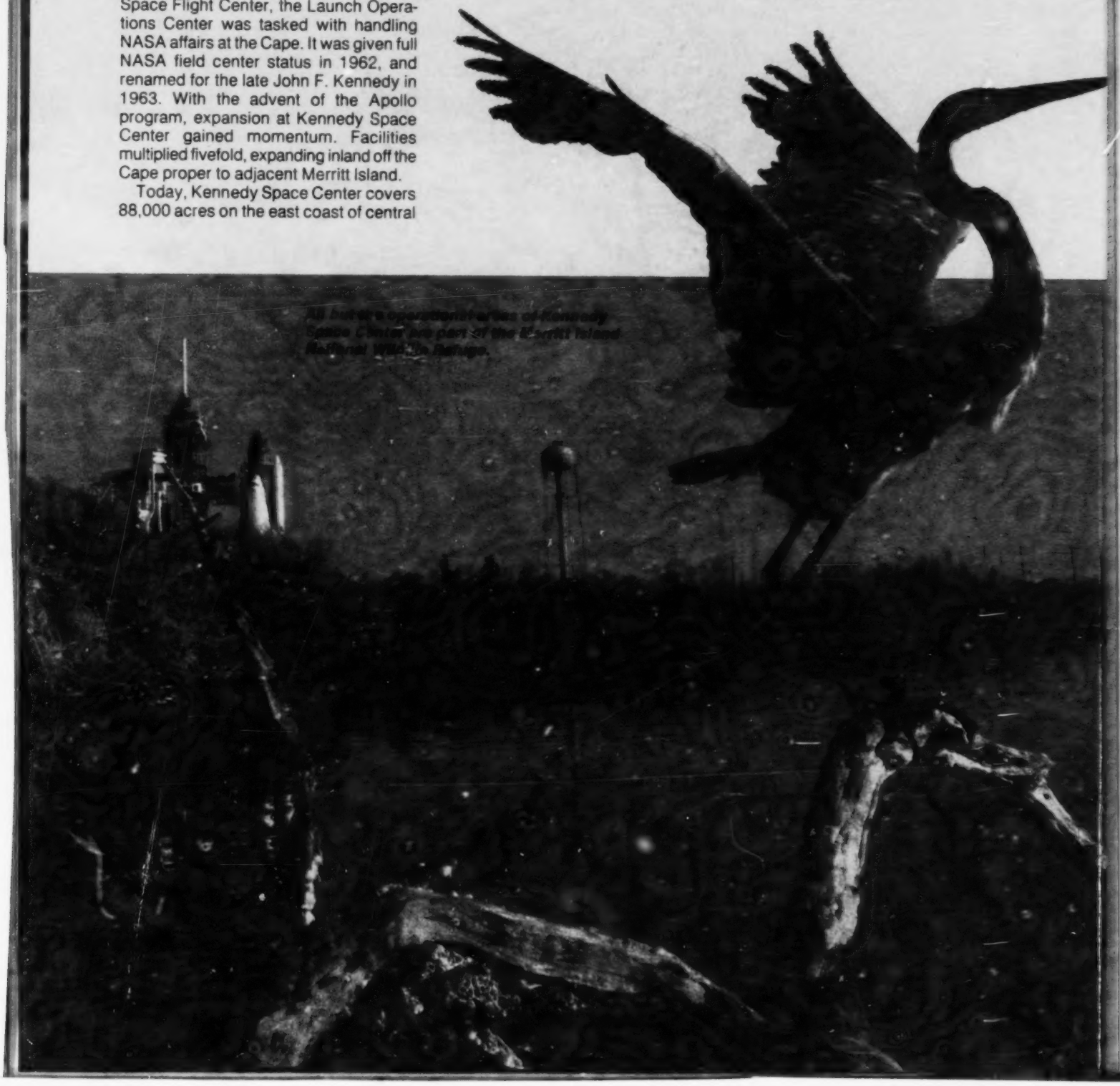
Nearly every expansion in launch capability has been accompanied by a new launch pad or some other form of facilities expansion. NASA's Launch Operations Center, which was formally established at the Cape in 1960, has grown up quickly. Originally a field office of the Marshall Space Flight Center, the Launch Operations Center was tasked with handling NASA affairs at the Cape. It was given full NASA field center status in 1962, and renamed for the late John F. Kennedy in 1963. With the advent of the Apollo program, expansion at Kennedy Space Center gained momentum. Facilities multiplied fivefold, expanding inland off the Cape proper to adjacent Merritt Island.

Today, Kennedy Space Center covers 88,000 acres on the east coast of central Florida. Complex 39, the centerpiece of the Apollo-era expansion, includes a number of new facilities, among them the mammoth Vehicle Assembly Building (VAB), which is visible from a distance of several miles and reportedly encompasses the largest enclosed space in the world. The 525-ft.-tall VAB was designed to accommodate the long and lean Saturn/Apollo vehicle, and today it is used to mate the shuttle orbiter with its 15-story external fuel tank and solid rocket boosters.

Other Complex 39 facilities include three mobile launcher platforms, upon which the shuttle systems are assembled before being moved to the launch pads, 39A and 39B. Both pads were built for Apollo launches, and their fixed service structures and other ground support equipment were modified for the shuttle program.

The job of moving the assembled shuttle system to the pad for launch is accomplished by crawler-transporters roughly the size of baseball diamonds. The crawler-transporters are powered by two diesel engines and move forward on four double sets of Caterpillar-like metal belts. Each tread of the metal belts weighs a ton, and fully loaded with the shuttle, the crawler-transporter weighs a whopping 3½-million tons.

Needless to say, it's not a quick sprint from the VAB to the launchpad. The trip takes nearly all day and progresses at the rate of one-half mph. Computer-controlled hydraulics keep the crawler's surface, and the shuttle system, level during the three-mile march to the pad. ►



MTS
TestingNews
Materials Testing Edition
Vol. IV, No. 9

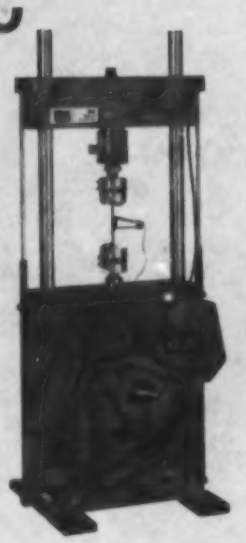
The MTS 810: Versatile Test Automation Beyond a PC

The New MicroProfiler™ Provides Added Flexibility to Material Testing

Automation. The new MTS 810 material testing system now offers a new automation package called MicroConsole™ PLUS. This desk-top controller comes with special software packages—the result of 20 years of material-testing experience. The test control and data acquisition capabilities are several steps beyond a commercial PC.

The software is MTS System's special version of BASIC. The language is interactive and friendly, to give you versatility and flexibility. MicroConsole PLUS hardware includes a powerful microcomputer with 512 Kbytes memory, Winchester plus floppy disc drives, printer and more. You can get application software from fracture mechanics through tensile testing and more. Send for details.

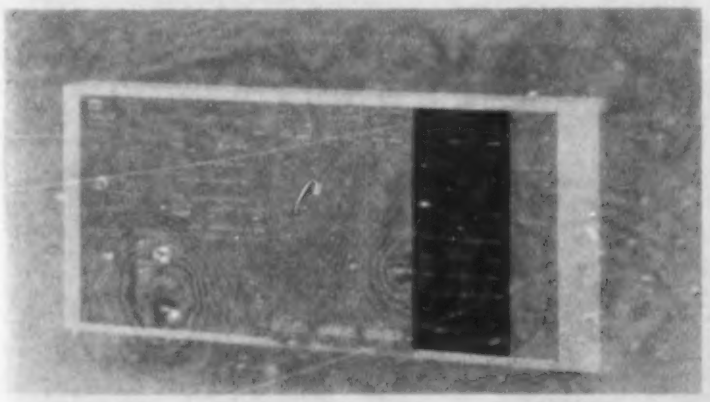
NEW VERSATILITY. The 810's new MicroProfiler digital waveform generator adds versatility and flexibility to testing. This microprocessor-based unit generates and stores an array of test profiles (56 Kbytes RAM storage), blocks (up to 90) and stores nine test programs WITHOUT THE NEED FOR A COMPUTER and with very high resolution.



MTS 810 Load Frame

Now it's easier to perform tests like tension, compression, bend, fatigue and fracture. Easy operation—pushbutton selection of 3 modes—programmed, direct and remote. An 18 bit digital-to-analog converter gives you high resolution. And you can select 1 of 9 rates at the touch of a button from a remote location.

The unique performance of the MTS MicroProfiler allows you to perform material tests which cannot be done with an ordinary function generator. Easy installation—nearly immediately operable. Send for more details.



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The MicroProfiler™ is the clear dark area in this photo of the MTS 458.20 MicroConsole.™

MicroProfiler™ Waveform Examples

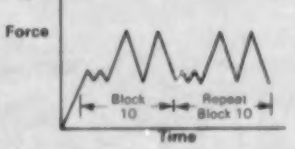

Figure 1. Block Cycle Test for Flight Simulation.

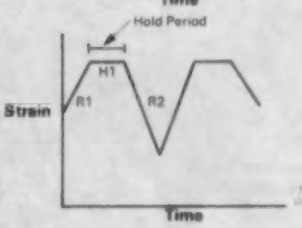

Figure 2. Strain Cycle Creep Typical of Power Generation Test Applications.

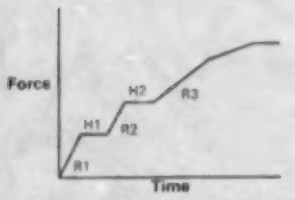

Figure 3. Waveform Used for Civil Engineering Structure/ Materials.

Free Extensometer Catalog describes broad test capabilities

This 24-page catalog details the variety of tests which MTS Extensometers can help you perform, such as fracture, bend, fatigue and tension/compression. New products also are described, such as: clip-on gage for testing in hostile environments; averaging axial and biaxial-axial extensometers; axial-torsional extensometers and more. Send now for this information-filled catalog.

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Rock, soil, ice, concrete test capabilities in free brochure

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Kennedy

Applying Technology

Beyond the rockets, launchpads, buildings and ground support hardware, a wealth of related technology has grown up around the launch activities at the Cape. While much of it was developed to meet the specific requirements of assembling, integrating, testing and launching spacecraft, the technology spans a broad range of disciplines, from inorganic coatings that preserve launch structures to programming languages and expert systems.

Computer systems and software development is one area where NASA deserves and in fact receives a good deal of credit. During the '70s, NASA and its contractors advanced a new generation of fail-safe software for the shuttle's on-board computer system. At Kennedy Space Center, advances in networking capability and in software development combined to form the Launch Processing System, an elaborate computer universe that automatically performs the bulk of shuttle checkout and launch functions.

Kennedy Space Center's innovative Common Data Buffer System was developed to provide the communication interfaces necessary to maximize the parallel processing capabilities of some of the system's newer computers. The flexible data buffer system allows many different brands and varieties of computers to interact in an efficient and error-free manner, greatly enhancing the speed with which shuttle checkout, testing and launch operations take place.

Another computer systems development tied to the shuttle era is GOAL, one of the first near-English programming languages. GOAL was developed to avoid the translation problems that can arise between the engineers who develop shuttle checkout and test procedures, the programmers who encode them, and the technicians who perform the actual operations. Using GOAL, engineers were able to write their own procedures into the software, and from there they could be followed through directly by technicians.

The computer systems development that took place at Kennedy Space Center throughout the '70s and early '80s was designed to provide specific responses to the equally specific questions posed by the implementation of the new space transportation system. Questions such as how do you process and control the shuttle? how do you integrate the largest distributed computer system in the world? and how do you circumvent the translation problems between systems engineers and technicians were addressed through applied technology development projects.

In the '80s, technology applications projects continue to command a great deal of attention and effort at Kennedy Space Center. The focus is on the development of technology-intensive (as opposed to manpower-intensive) methods for assembling, servicing, testing and launching the space shuttle. The ultimate goal of these projects is to reduce to number of ground operations man-hours per space shuttle flight by 50%, at the same time reducing shuttle turnaround time substantially.

A KSC technician inspects the thermal tiles on Discovery's wing.

Expanding the Technical Base

Kennedy Space Center's Robotics Applications Development Laboratory is conducting studies to determine where the implementation of robotic systems could reduce the number of man-hours needed to assemble, service and test the shuttle prior to launch. Different time-critical, hazardous and repetitive labor-intensive operations that could potentially be handled partially or completely by automated robotic systems have been identified, and these are currently being evaluated by laboratory personnel. Time-critical applications include the assembly of the space vehicle and the external tank, and the installation and integration of payloads. The application of robotic systems to hazardous tasks focuses on the loading and unloading of the hypergolic and cryogenic propellants that fuel the shuttle. A number of repetitive tasks, such as spot welding, that could eventually be performed by robots are being studied as well.

Kennedy's Robotics Applications Development Laboratory is currently equipped with an electrically driven, ASEA robot composed of a six-axes arm with interchangeable end-effectors or "hands." It is controlled by a user-friendly computer brain that allows it to carry out its functions autonomously, rather than being teleoperated by a person. The prototype robot will supply the baseline data upon which more complex tasks and integrated "smart" robotic systems can be developed. It is expected that both the space station and the next generation space transportation system will rely heavily on robotics and other automated systems, so beyond its immediate applications orientation, the Robotics Application Development Labora- ►

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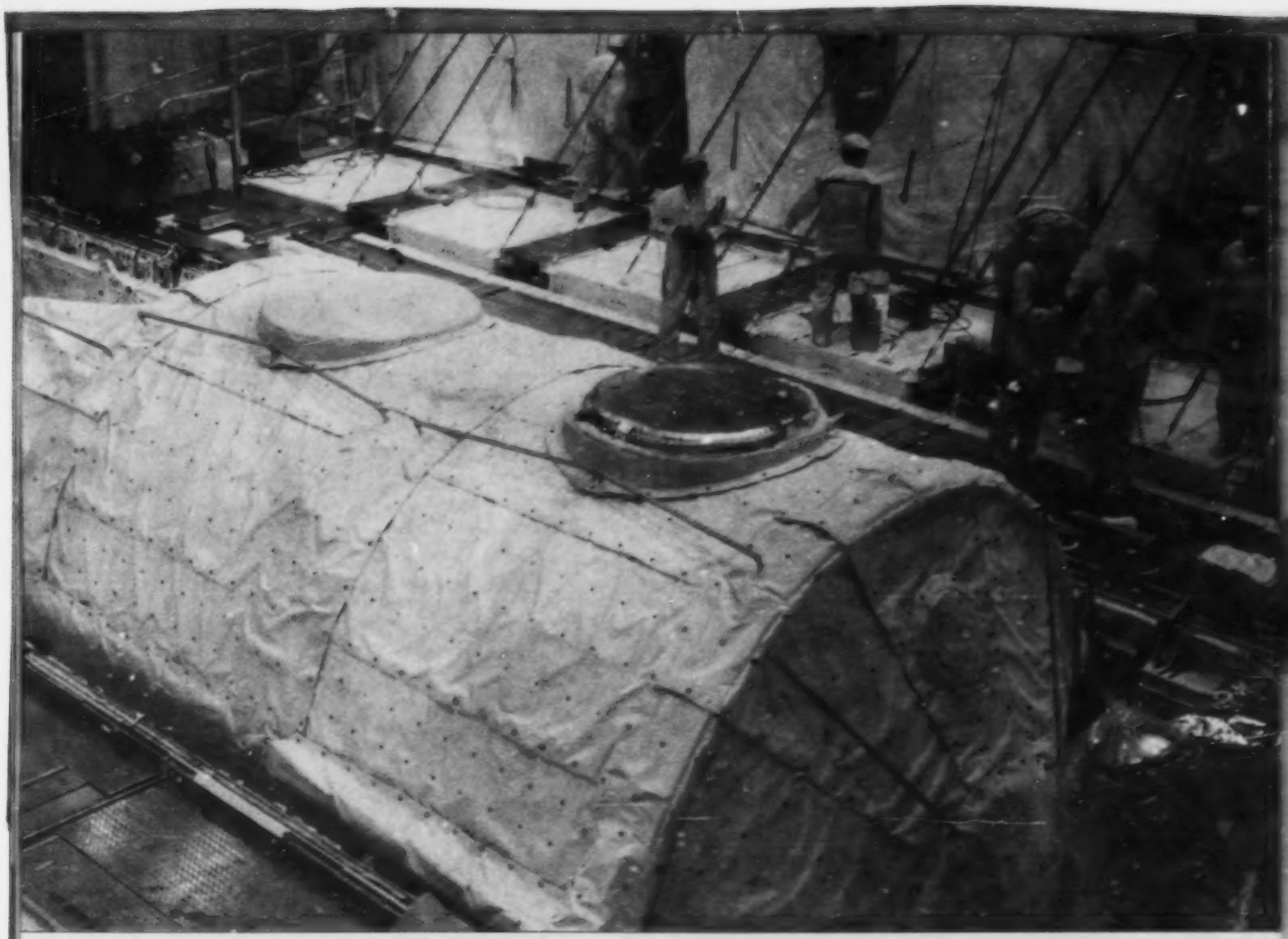

Technicians at KSC's Orbiter Processing Facility install Spacelab in the shuttle cargo bay.

tory is coordinating intercenter work on these future projects.

Artificial intelligence, particularly knowledge-based expert systems, is another technology Kennedy Space Center is developing in the interest of streamlining and improving assembly, servicing, test and launch operations. Activities in this area focus on control and monitor expert systems and information management expert systems.

Development of the LOX expert system for controlling, monitoring and real-time diagnostics of KSC's liquid oxygen loading system began in 1983. The LOX system was to have gone on-line in the firing room in November 1986, but owing to the current shuttle stand-down, this date has been postponed.

In the meantime, other expert systems are being developed, using IBM AT's and Symbolics computers. KATE, the knowledge-based automatic test equipment project, uses LES (the on-line launch-pad environment expert system) as a baseline for its automated hardware testing and control system. KATE is capable of a variety of functions, including multiple command control, multiple failure diagnosis and adaptive learning through reading and observation. The system is designed to identify failed test system components, determine alternate solutions that will allow the test to proceed, and restore the process by commanding the activation of redundant components.

EMPRESS, the expert mission planning and replanning scheduling system, is designed to capture the expertise of those individuals who plan, construct and maintain shuttle mission schedules. EMPRESS is a subset of a larger planning system in that it deals specifically with payloads manifested to fly on the shuttle. EMPRESS defines the time, resource and task requirements associated with particular payloads, and determines how particular payloads fit into the overall scheme of mission planning.

The near-term goals of Kennedy Space Center's artificial intelligence, expert systems, and robotics development and applications programs involve upgrading the shuttle processing systems and software that have, in the space of a decade, become antiquated. The long-term goal is to create the ultimate paperless management system for the space shuttle. Multiple, interactive expert systems will perform checkout, test and launch procedures of vehicles that have been assembled, fueled and serviced in part by robots.

The proposed space station poses another set of unique questions to Kennedy Space Center. What is the appropriate programming language for user interface? How can artificial intelligence and expert systems be applied to streamline space station assembly, checkout, test and operational procedures? What roles can best be performed by robots and other automated systems?

Again, Kennedy Space Center's expertise in developing and applying innovative technology will be called upon to answer the unique and task-specific questions that arise at the edge of the last frontier.

Finally, though, there is no question regarding what will be Kennedy Space Center's most pressing task in the months ahead. Restoring the space shuttle program to safe and regular operational capacity is a national priority, and Kennedy's role in this process will be vital. All things considered, the people at Kennedy Space Center are optimistic. The somber aura that descended in the wake of the Challenger accident has begun to dissipate, and while a subdued and sober quality is still very much in the air, the atmosphere there is charged with the combination of determination, perseverance and vision that makes spaceflight possible in the first place. □

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Before someone sells you a lab quality wideband instrumentation recorder, we'd like you to ask a simple question—What about tomorrow?

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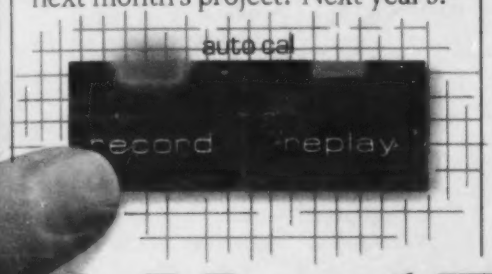

A Head To Head Comparison

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What about reliability and calibration?

Not to mention a close look at the bottom line—including the value of your time.

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Every signal channel adjustment—from bias and record currents to replay equalization, is fully automatic. To IRIG Standards.

What does that mean to you?

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	Racal Storehorse	Honeywell 101	Sabre 9
Calibration/ Equalization	Fully Automatic Record Calibration and Replay Equalization	Manual Calibration and Equalization with Internal Verification	Manual Calibration and Equalization with Internal Verification
Tape Path	Planar Transition Device, No Tape Twist and Stretch	Traditional Approach with Tape Twist and Stretch	Traditional Approach with Tape Twist and Stretch
Remote	IEEE 488 & RS232 Access to all Deck Functions and Signal Channel Parameters	IEEE 488 *or* RS232, with Limited Selection of Functions	IEEE 488 *or* RS232, Single Option Only
Size	Up to 42 Record/ Reproduce Channels in One Portable Housing	Additional Chassis Required	Additional Chassis Required

IEEE 488 AND RS232 INTERFACES

Sure the others can handle IEEE 488 and RS232, after you add the extra-cost interfaces.

VDU constantly monitors recording and machine parameters.
Calibrate and equalize 42 channels in 6 minutes.
15/32 to 120 inches/second, 2 to 42 tracks.
Automatic lockout and positive cabinet pressure all but eliminates dust contamination.

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Circle Reader Action No. 397

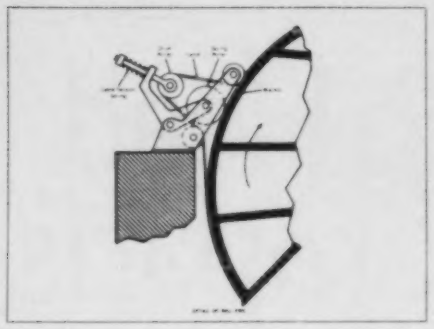
New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 29). NASA's patent-licensing program to encourage commercial development is described on page 29.

Retractable Sun Shade

A mechanism that unfurls a blanket to form an arched canopy, developed for Space Shuttle missions, can be adopted to the shading of greenhouses, swimming pools, and boats. A window-shade type spring roller contains a tough, opaque polyimide blanket, which is taken up by a rotating cylindrical frame and held over the area to be shaded (see figure). When the roller motion is reversed, the blanket is drawn by its return spring back into the spring roller. Powered manually or by an electric motor, the drive roller can be stopped at any point to provide partial shade instead of full shade.

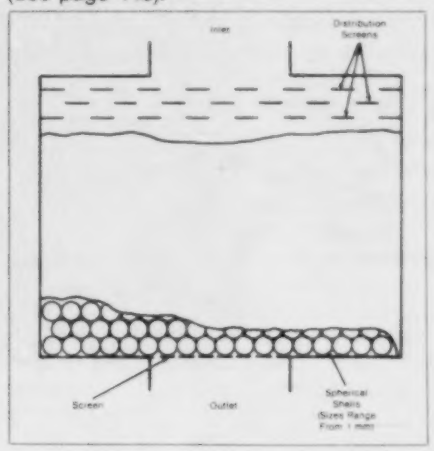
(See page 94.)



Filter Bed of Packed Spheres

A proposed filter would be constructed from densely packed spheres restrained by screens (see figure). Hollow gas-filled plastic or metal spheres would normally be used. These can be manufactured within a 10-percent diameter tolerance. Normally, all the spheres in a filter would be of the same nominal diameter. The dimensions and surface coatings of the spheres would be selected to provide the desired physical and chemical properties. Such a filter could be used as a sieve to pass only particles smaller than a given size or to retain particles larger than that size. In the case of cells or other biological materials, the new filter may be preferable to older screen-type filters, which can damage the cells or other filtrate particles.

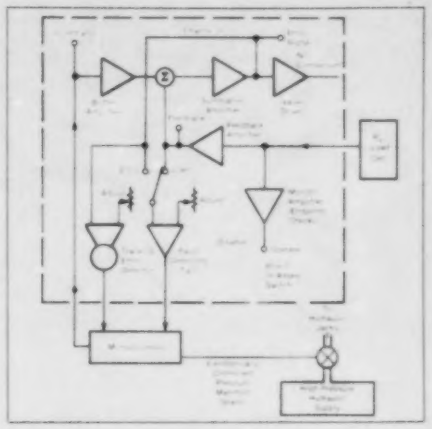
(See page 140).



Hydraulic Shutdown Monitor

A simple modification enables a commercial electronic load controller to be used in an electromechanical system for load monitoring and overload shutdown. A four-pole, double-throw switch is added to the front panel of the controller to disable the tracking-error and endpoint-error circuitry yet still retain the overload-detection capability. In the "disable" position, the added switch overrides functions of the controller that would prevent automatic shutdown on overload during friction tests (see figure). In the "operate" position, the switch allows the controller to operate in its normal fashion. Previously, it was necessary to use adjustable-voltage-level detection equipment connected with cables to the hydraulic "dump" or shutdown circuitry in the controller.

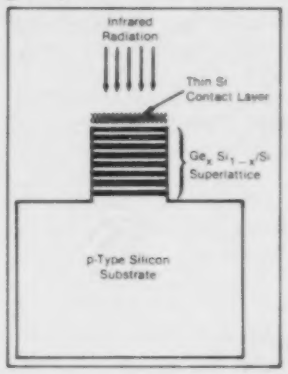
(See page 30).

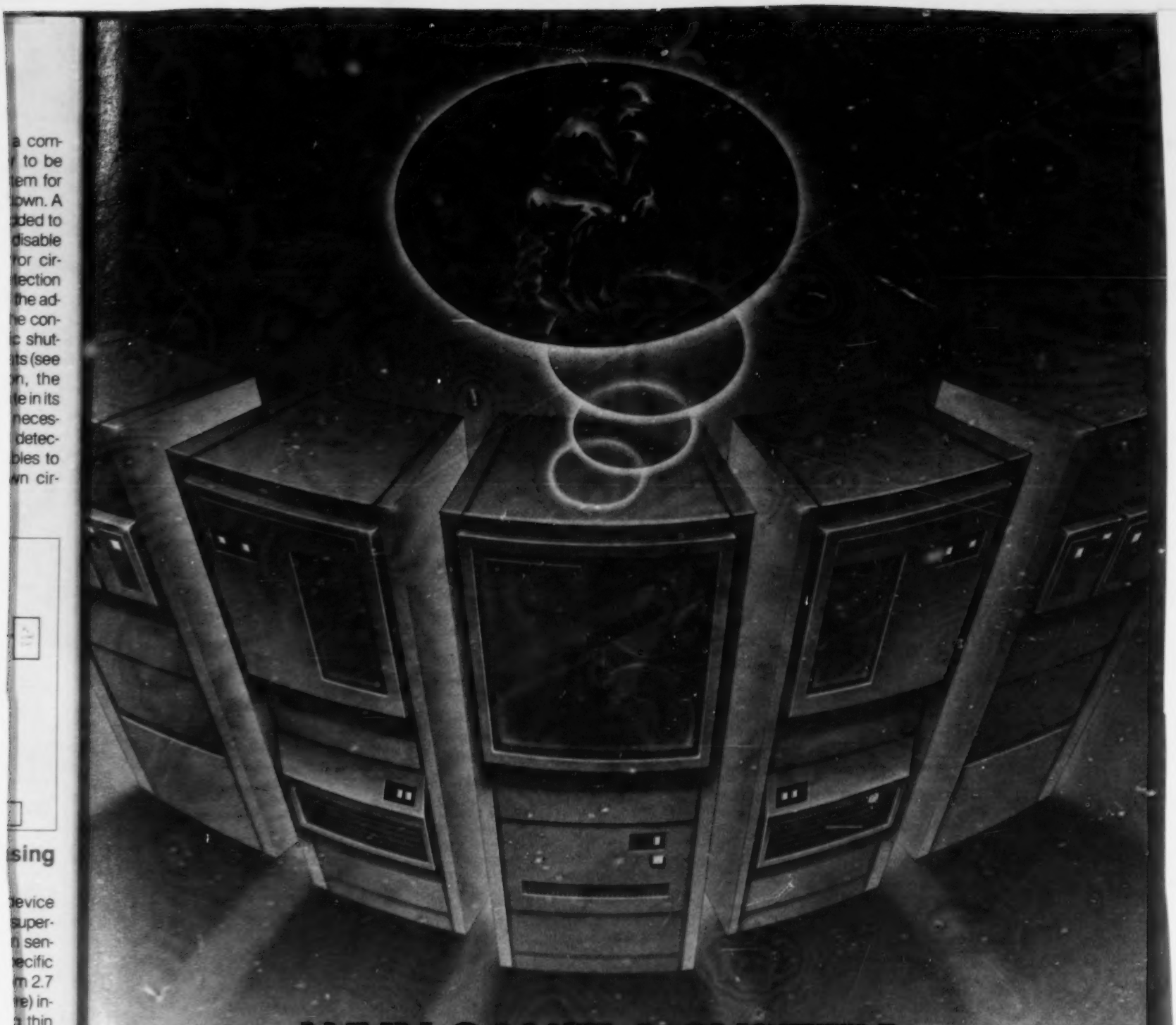


Tailorable Infrared Sensing Devices

A proposed infrared sensing device using a Ge_xSi_{1-x}/Si strained-layer superlattice may offer enhanced detection sensitivity and could be tailored for a specific cutoff wavelength over the range from 2.7 to about 50 μm. The device (see figure) includes a large number of alternating thin layers of Ge_xSi_{1-x} and Si deposited on a silicon substrate by molecular-beam epitaxy. When an electric field is applied across the stack, it acts as a detector for infrared photons. Such a structure could find a wide range of applications in robotics, space exploration, and terrestrial surveillance.

(See page 36).





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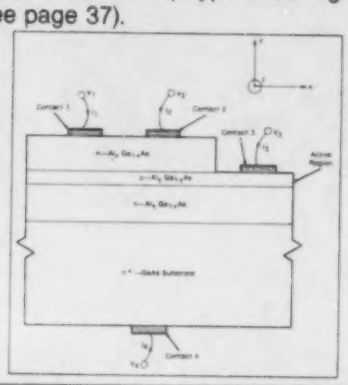
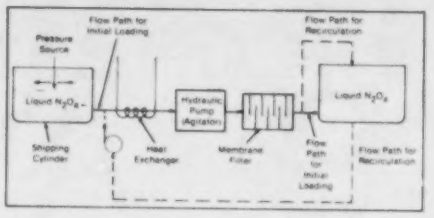
Semiconductor Laser With Two-Dimensional Beam Steering

The proposed modification of a monolithic semiconductor injection laser capable of one-dimensional electronic beam steering should enable the deflection of its beam in a second direction. Such a laser chip could provide beam pointing or raster scanning for applications in optical communications, data processing, image scanning, and optical ranging. Two-dimensional electronic steering of the beam would be achieved by adding electrode (contact) 3 to a laser (see figure) that was previously capable of one-dimensional beam steering. The laser beam would come out of the page in the z direction from the p-type base region.
(See page 37).



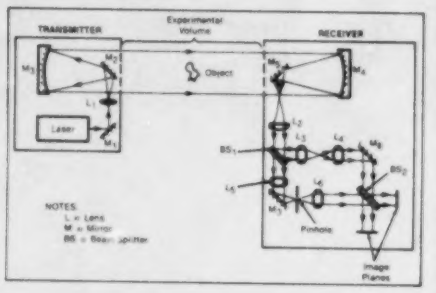
Cleaning of Liquid N_2O_4

A technique developed for cleaning of liquid N_2O_4 may be adaptable to the cleaning of a variety of industrial fluids, including fuels. Metal nitrate impurities are precipitated from N_2O_4 by cooling the N_2O_4 in a heat exchanger and then passing it through a hydraulic pump. The precipitate is then removed by a fine membrane filter (see figure). This process, used in filling the facility storage tank, is repeated several times by the recirculation of the stored N_2O_4 to remove as much of the nitrates as possible. This system typically lowers the iron content in liquid N_2O_4 from as high as 5.0 parts per million to about 2.0 or fewer parts per million.
(See page 103).



Interferometer for Observing Compressible Flow

A new optical interferometer (see figure) enables the instantaneous visualization of compressible fluid flows. Because it is relatively immune to vibration, the unit is well suited to the observation of flows over models in large wind tunnels. By noting the relationships between fringe shifts, refractive indices, and densities, an experimenter can map the flow-field density contours. The interferometer can give a quantitative, time-resolved characterization of the flow field and has been demonstrated by producing images of the flow around a candle, a propane torch, a heated cylinder, and an oscillating airfoil in a wind tunnel.
(See page 60).



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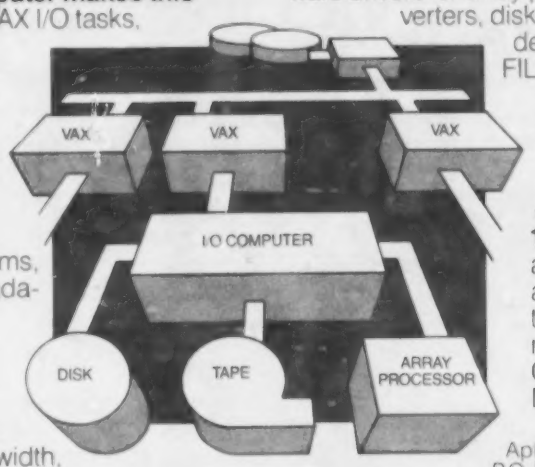

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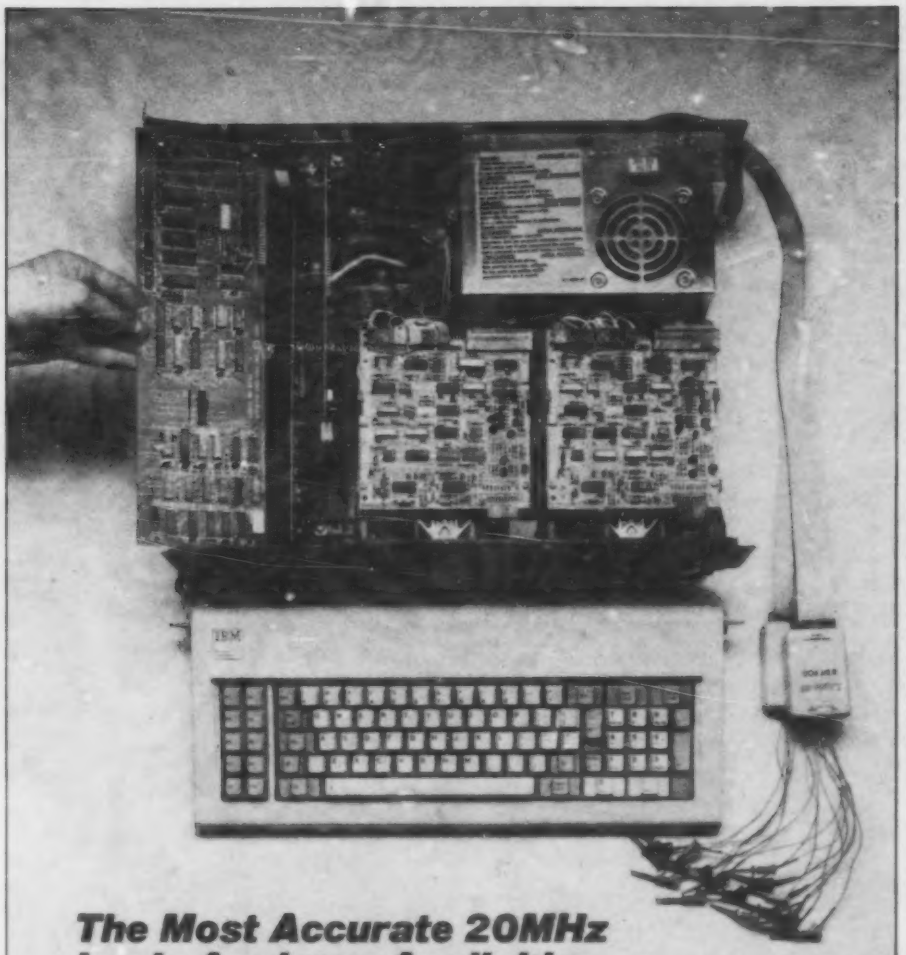

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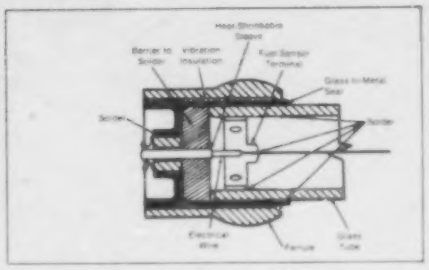
26 **Circle Reader Action No. 301**

New Alloy for Glass-to-Metal Seals

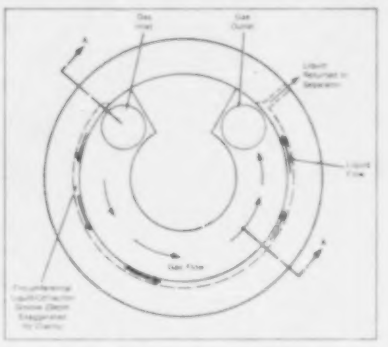
A new alloy — composed of about 60 percent iron, 40 percent nickel, and traces of six other elements — has a low coefficient of thermal expansion, $1.9 \times 10^{-6}(°F)^{-1}$ [$3.4 \times 10^{-6}(°C)^{-1}$]. Because the coefficient is close to that of KG-33 (or equivalent) glass, the alloy can be used in glass-to-metal seals without introducing excessive residual stresses. In addition, the alloy has potential for other applications in which low thermal expansion is important; for example, mechanical measuring devices and precise sliding parts that must function over wide temperature ranges. The alloy was developed as a replacement for Kovar (or equivalent) Fe/ NiCo alloy in a ferrule-and-tube assembly (see figure).

(See page 100).



Liquid Scavenger for Separator/Pump

A pump for hydrogen has been modified to remove moisture that condenses in the impeller stage and shunt it back to the earlier centrifugal separator stage for removal. Normally, the separator stage removes water droplets from an incoming mixture of hydrogen gas, water droplets, and water vapor. In the unmodified pump, however, additional condensation sometimes occurs in the pump stage. The moisture-removal problem was solved by adding a shallow circumferential groove and a small exit hole to the impeller chamber (see figure). The circumferential groove leads to an exit hole near the high-pressure outlet. As the impeller disk (not shown) rotates, it flings water droplets that have condensed in the pump toward the groove. Aerodynamic drag drives the water around the groove to the exit hole. (See page 92).



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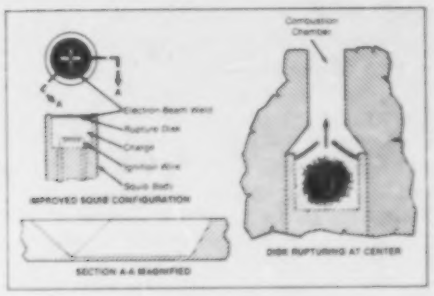
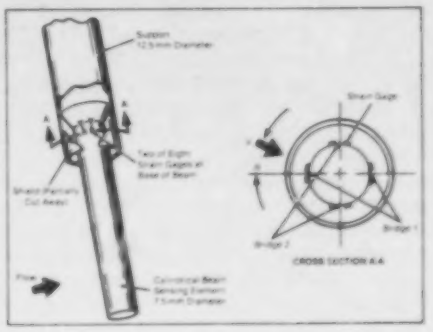
Centrally-Rupturing Squib-Closure Disks

An improved squib rupture disk would insure that the squib explosion is directed toward the center of a combustion chamber. This can obviate the use of oversize squib units that can cause undesirably large impulses. In the new design (see figure), the center of the rupture disk contains a cruciform indentation in which the thickness is reduced to about 0.5 mil (0.013 mm). This reduces the strength of the center of the rupture disk in the same manner as that of the pull tabs on beverage cans; therefore, the disk will fail predictably in the center, causing a predictable flow of combustion products toward the center of the combustion chamber. (See page 93).



Omnivector Probe Measures Airflow

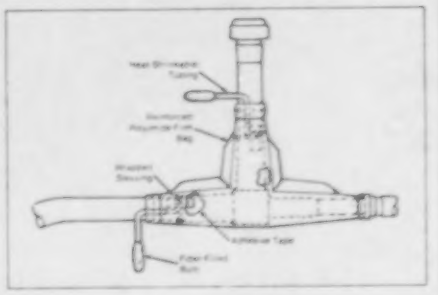
A probe (called an omnivector anemometer) has a fixed-position sensing element capable of simultaneously measuring steady and unsteady velocity head and flow direction of a moving fluid over a complete 360-degree angle in two-dimensional flow. The sensing element of the omnivector anemometer (see figure) is mounted on the end of a support tube, which is necessary for inserting the sensing element into the flow field. The main element of the anemometer is a drag body consisting of a cylindrical tube upon which are mounted eight miniature strain gages near the base and electrically connnected in the form of two four-arm Wheatstone bridges.
(See page 84).



Hydraulic-Leak Detector for Hidden Joints

An indicator reveals leaks in hidden fittings on hydraulic lines. It allows fast inspection of joints without disassembly and can be used in aerospace, petroleum, chemical, nuclear, and other hydraulic applications where removing covers for inspection is impossible, difficult, or time-consuming.

The indicator consists of a wick wrapped at one end around the joint to be monitored (see figure). The wick, made of Kevlar (or equivalent) aramid sleeving, absorbs hydraulic fluid leaking from the joint and transmits it to the opposite end where it is visible to an inspector. At the end of the wick is a bulb filled with fibrous insulation to make the fluid more evident as a discoloration of the outside end of the wick.
(See page 102).



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Electronic Components & Circuits

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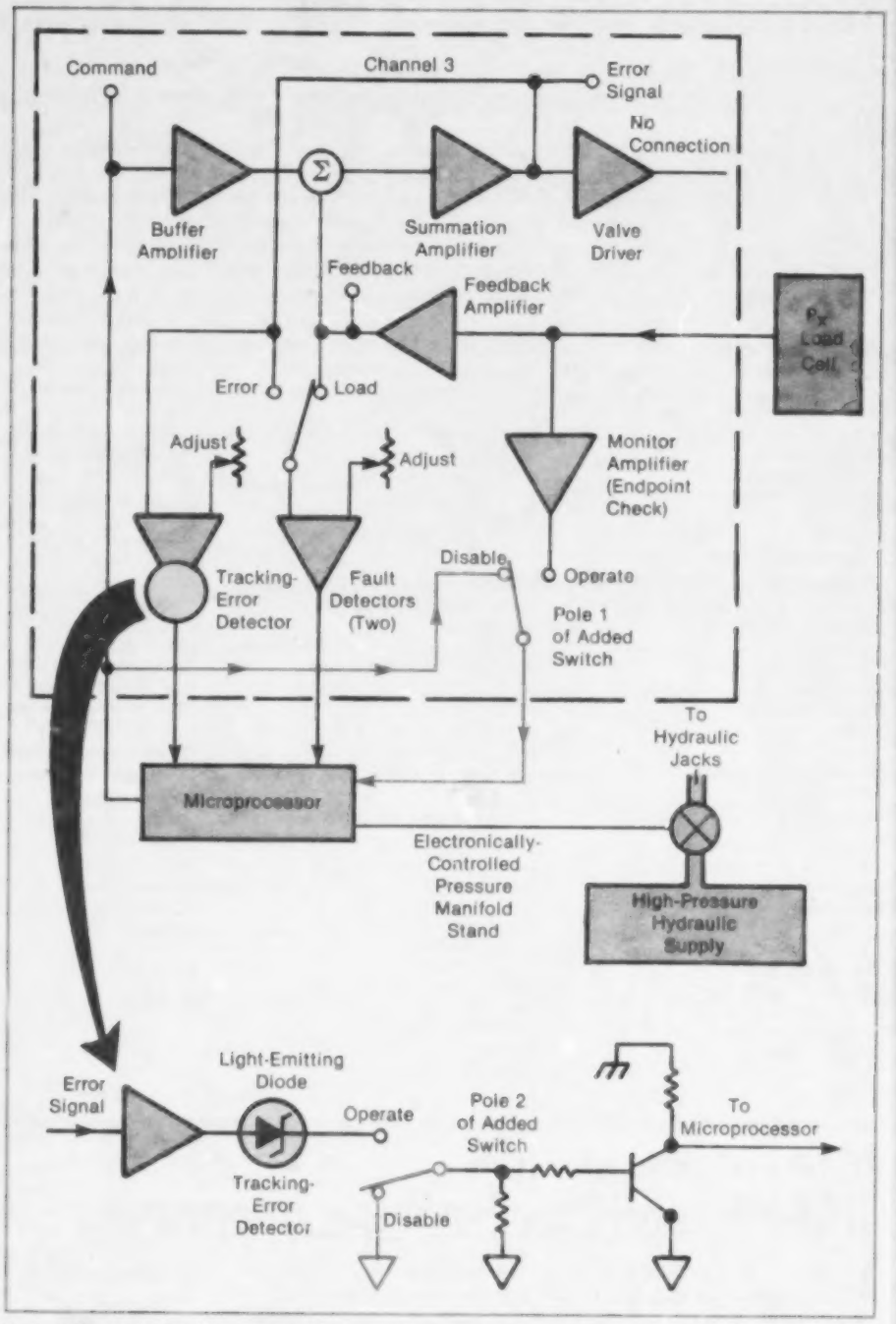
Hydraulic Shutdown Monitor

Adding a switch allows inappropriate control actions to be overridden.

Lyndon B. Johnson Space Center, Houston, Texas

A simple modification enables a commercial electronic load controller to be used in an electromechanical system for load monitoring and overload shutdown. A four-pole, double-throw switch is added to the front panel of the controller to disable the tracking-error and endpoint-error circuitry yet still retain the overload-detection capability. Previously, it was necessary to use adjustable-voltage-level detection equipment connected with cables to the hydraulic "dump" or shutdown circuitry in the controller.

During a friction test, for example, the



In the "Disable" Position, the added switch overrides functions of the controller that would prevent automatic shutdown on overload during friction tests. In the "operate" position, the switch allows the controller to operate in its normal fashion.

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Circle Reader Action No. 359

specimen is stroked in the x direction while it is subjected to a load in the y direction. Data-acquisition equipment records loads in the x and y directions, P_x and P_y, respectively, and divides P_x by P_y to determine the coefficient of friction. It is necessary to monitor P_x and shut down the hydraulic pressure when P_x exceeds a predetermined value, thus preventing damage to the specimen or to the test equipment. The unmodified controller, however, would perceive an increase in P_x as an "endpoint-check" error or a "tracking" error, and its logic circuits would instruct the test machine to hold its commanded load instead of shutting it down.

The addition of the switch to the P_x channel of the controller disables the endpoint-error and the tracking-error circuits (see figure). This allows the controller to use its fault-detection circuits to dump the hydraulics in case of a P_x overload while allowing tests to continue on other channels with full endpoint and tracking control.

Pole 1 of the switch puts the command signal (which orders the load on the specimen) on the endpoint-check line (which monitors the load on the specimen) to the controller microprocessor. Thus, when the microprocessor compares the command signal with the endpoint-check signal, it finds agreement between the two and does not generate an endpoint-error signal.

Pole 2 of the switch grounds the base of the tracking-error output transistor. This prevents the tracking-error circuit from causing a hold-to-load signal to be sent to the test machine.

Pole 3 of the switch (not shown) turns on an "errors disabled" indicator on the front panel. Pole 4 (not shown) changes a meter switch from the "monitor ouput" line to the "command" line. Neither of these two poles affects the controller function: They are included for the operator's benefit only.

This work was done by Scott T. Fleming and Douglas B. Harrington of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 56 on the TSP Request Card.*
MSC-20796

Controlling a Four-Quadrant Brushless Three-Phase dc Motor

The motor drives or brakes regeneratively on command, in either direction.

Marshall Space Flight Center, Alabama

A control circuit (see figure) commutates the windings of a brushless, three-phase, permanent-magnet motor operating from a dc power supply. With a single analog command voltage, the controller makes the motor accelerate, drive steadily, or brake regeneratively, in a clockwise or counterclockwise direction. The controller is well suited for use with energy-storage flywheels, actuators for aircraft-control surfaces, cranes, industrial robots, and other electromechanical systems requiring bidirectional control or sudden stopping and reversal.

Position sensors placed on the shaft provide signals that indicate the position of the rotating magnets with respect to the stationary windings. These signals are square waves that differ from each other in phase by 120°. The high interval of each position signal determines when the switching transistors of the corresponding winding are turned on.

At any given instant, winding current is being conducted by only one pair of diagonally-located switching transistors. The transistor-pair configuration changes every 60 electrical degrees of shaft rotation. For example, when the shaft position enters the first 60° (electrical) of winding A while moving clockwise in the accelerating motor mode, current is conducted through Q_1, windings A and B, and Q_5. During the second 60°, Q_5 is turned off, and the current path is through Q_1, windings A and C, and Q_6.

Resistors R_1, R_2, and R_3 provide feedback voltages proportional to the winding currents. These current-feedback signals are alternately sampled during 120° intervals, inverted as necessary, and compared with the current-command signal

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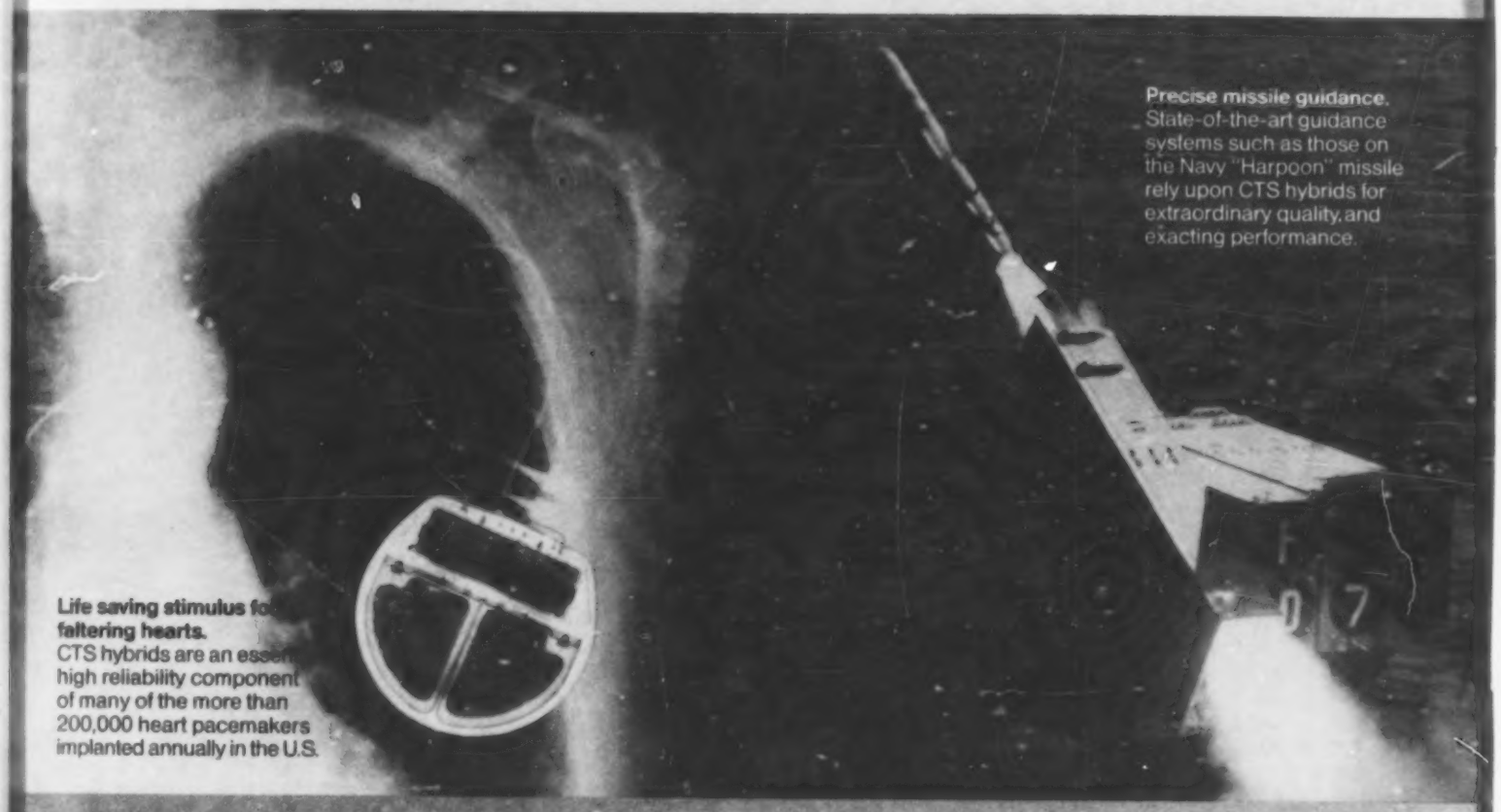

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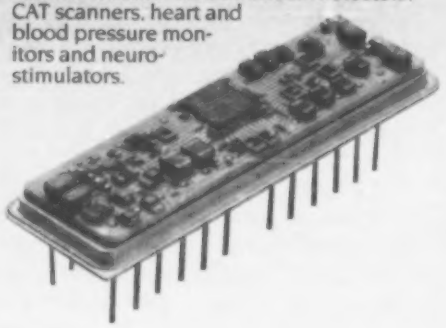

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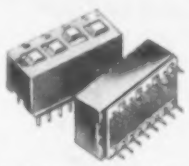

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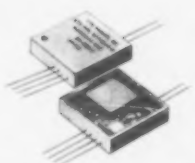

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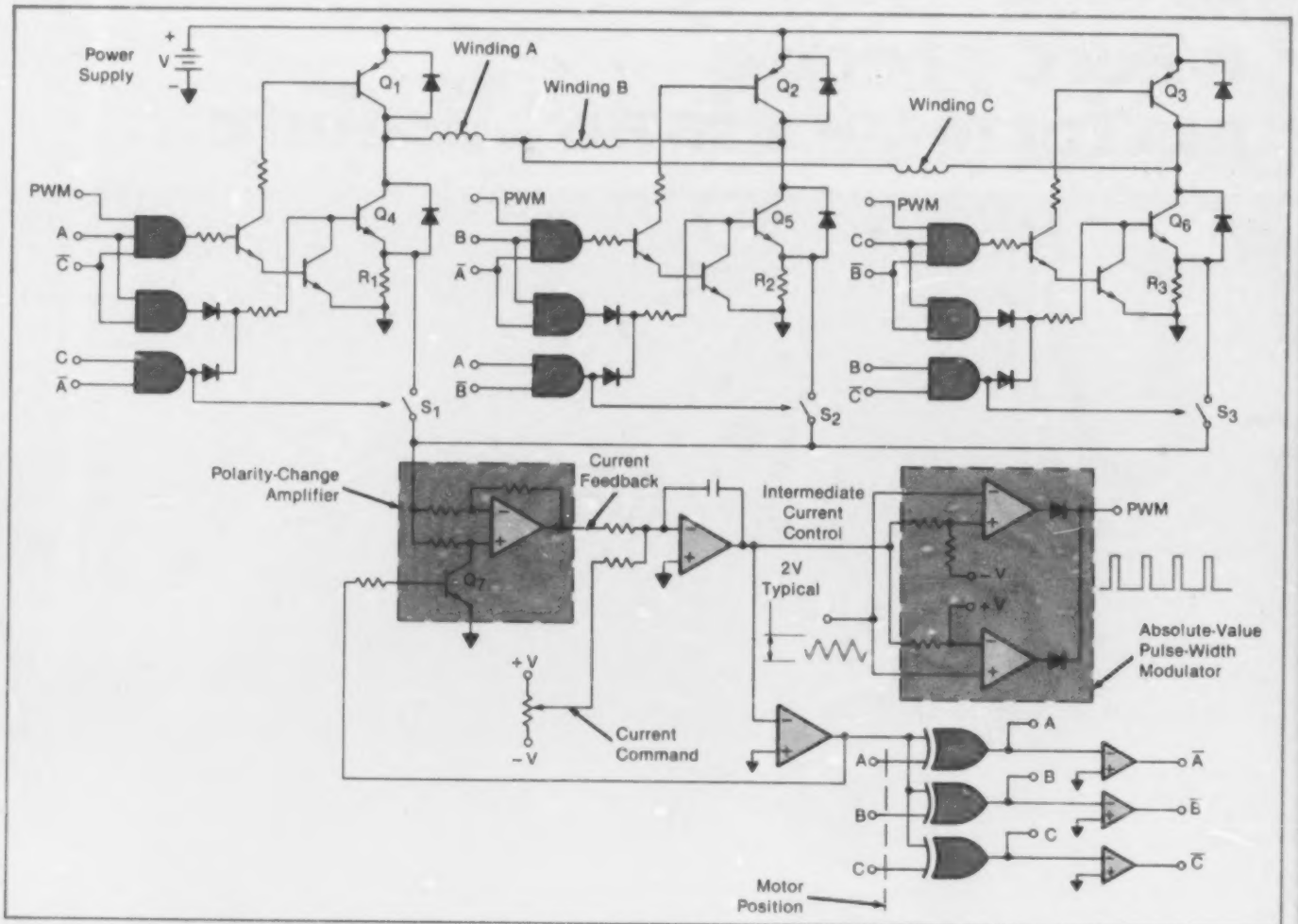


With this **Motor-Control Circuit**, a three-phase permanent-magnet motor is made to accelerate or brake regeneratively in either direction by setting the magnitude and polarity of the current-command voltage.

(regardless of its polarity) to obtain an intermediate negative-feedback current-control signal. In the absolute-value pulse-width modulator (PWM), the intermediate signal is compared with a triangular wave of about 10 kHz. The resulting PWM output is a train of pulses, the durations of which are varied to turn the switching transistors on and off at intervals intended to produce the commanded current.

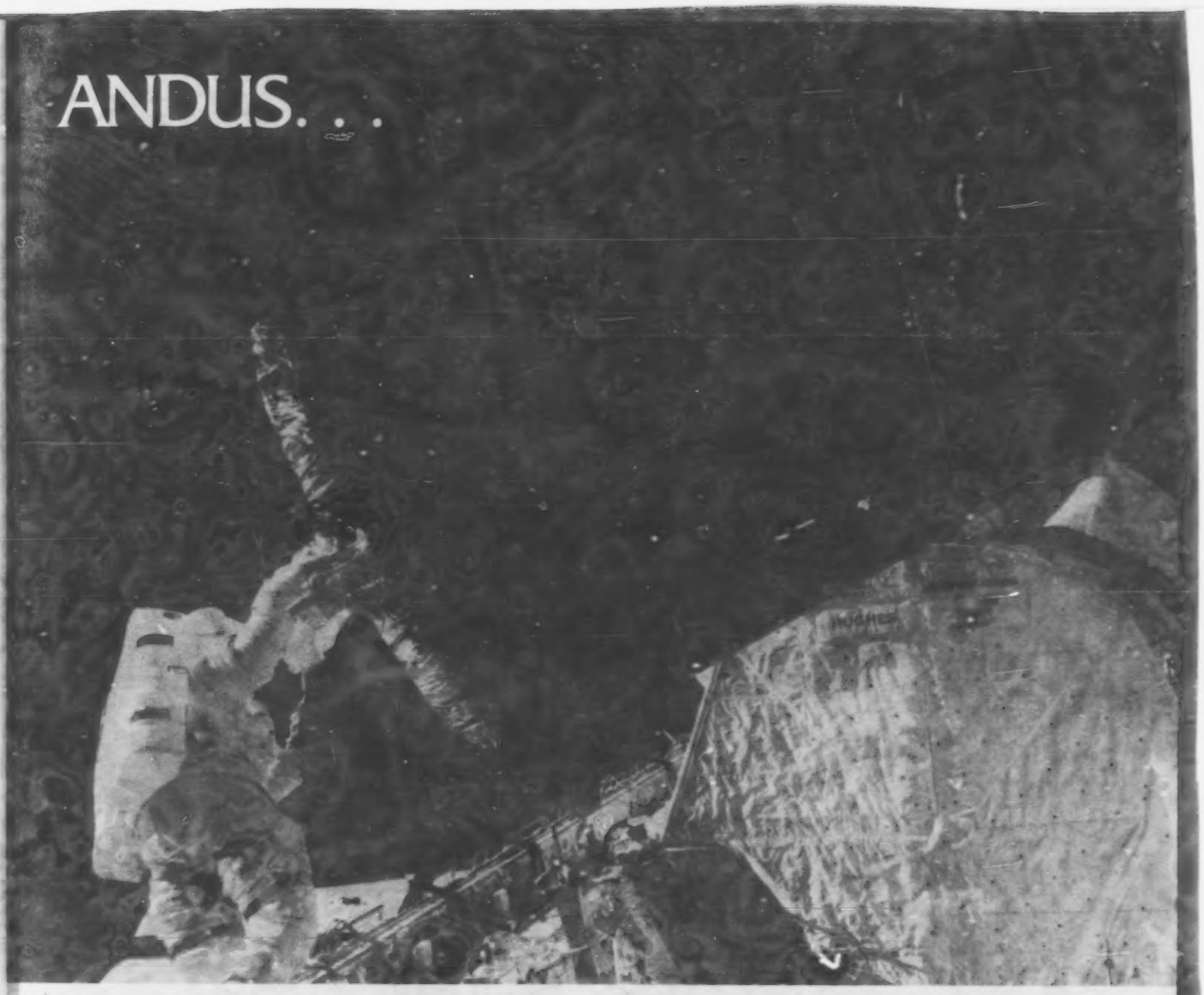
The lower transistor in each pair (for example, Q_4 for winding A) is turned on during the 120° that begin 60° after the cessation of the "on" period of the upper transistor of that pair. In addition, the lower transistor is turned off and on during the 120° when the upper transistor is being turned on and off, respectively.

The turn-on and turn-off times for each transistor are determined according to the current command and to the shaft position, direction of rotation, current, and back-electromotive force of the motor, as measured by the position and current sensors. For example, a current-command signal of one polarity causes acceleration or turning against a load in a clockwise direction, or braking from counterclockwise rotation, possibly followed by reversal into clockwise rotation. A current-command signal of the opposite polarity produces similar effects in the opposite directions.

In acceleration, the appropriate transistor pairs are connected in the sequence of pulses as the circuit attempts to maintain the commanded current from the supply to the motor. In braking, the motor acts as a generator, and the transistor pairs are connected in the pulse sequence as the circuit attempts to maintain the commanded current from the motor as it feeds power back to the supply. As the braking motor slows toward a stop, the back-electromotive force is no longer sufficient to maintain the commanded current: At that point, the circuit begins to feed current from the supply to the motor to continue the braking by maintaining the commanded current. Eventually, the motor may stop and begin to accelerate in the opposite direction. Thereafter, the circuit continues to maintain the commanded current, with the difference that the pulse sequence moves in the opposite direction among the windings, corresponding to the opposite motor rotation.

This work was done by Frank J. Nola of **Marshall Space Flight Center**. *For further information, Circle 48 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28080.



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Tailorable Infrared Sensing Devices

Proposed devices would consist of Ge_xSi_{1-x}/Si strained-layer superlattices on silicon.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed infrared sensing device using a Ge_xSi_{1-x}/Si strained-layer superlattice may offer enhanced detection sensitivity and could be tailored for a specific cutoff wavelength over the range from 2.7 to about 50 μm. Such a device could be fabricated on a silicon substrate together with sophisticated very-large-scale integrated circuitry, making it useful for a wide range of applications related to robotics, space exploration, and terrestrial surveillance.

The device (see Figure 1) includes a large number of alternating thin layers of Ge_xSi_{1-x} and Si. Such a structure can be grown using molecular-beam epitaxy; in the future, such other growth techniques as chemical vapor deposition might be used.

Figure 2 illustrates the energy-band diagram of a Ge_xSi_{1-x}/Si superlattice with a high concentration of dopant under an electrical bias voltage. The energy gap of Ge_xSi_{1-x} is lower than that of Si by an amount ΔE(x), which depends on the germanium content, x. As the superlattice gets richer in germanium, its energy gap decreases monotonically from that of silicon (1.1 eV) to that of germanium (0.66 eV). Although the lowest value of ΔE(x) can be zero (when $x = 0$), in practice the lowest ΔE depends on the temperature and for a practical device could be about 0.01 to 0.05 eV, depending on operating conditions; thus the new device could operate at wavelengths up to 50 μm. Good-quality Ge_xSi_{1-x}/Si superlattices with $x < 0.5$ grown by molecular-beam epitaxy already have been demonstrated; and theory indicates that in the future, high-quality superlattices with the full range of x (from 0 to 1) can be grown.

The mechanism of the new device is similar to that of the silicide Schottky-barrier detector, with the silicide film being replaced by the heavily-doped Ge_xSi_{1-x} semiconductor layer. A photon of energy greater than ΔE(x) excites a hole from the valence band of Ge_xSi_{1-x} to that of Si. The hole then drifts to the cathode under the influence of the applied electric field. Since the device has many charge-separation barriers, its detection sensitivity should be greatly enhanced. The device could be operated in an avalanche mode, under which the gain should be high and the response time very short.

This work was done by Li-Jen Cheng of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 52 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL. [see page 29]. Refer to NPO-16607.

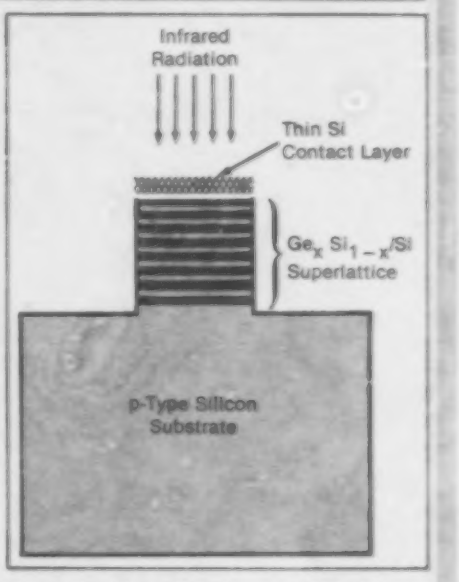


Figure 1. **Alternating Layers of Ge_xSi_{1-x} and Si** are deposited by molecular-beam epitaxy. When an electric field is applied across the stack, it acts as a detector for infrared photons.

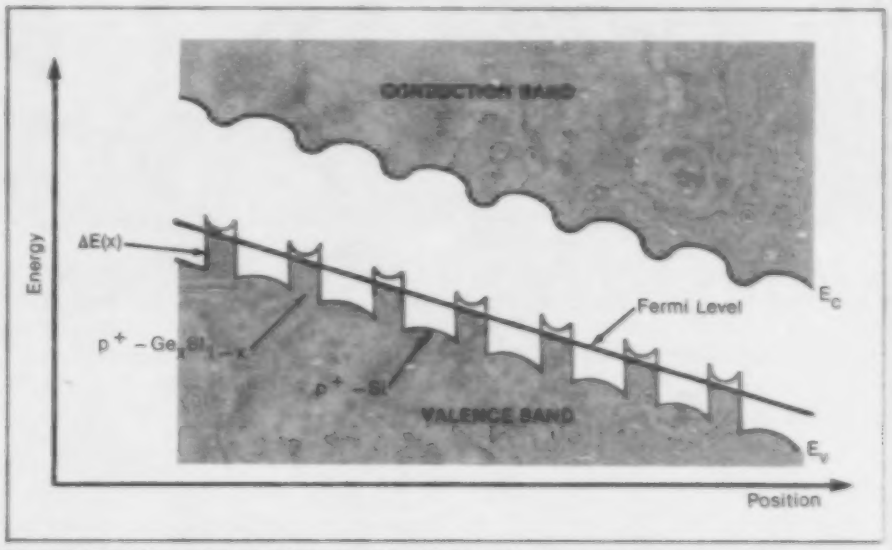


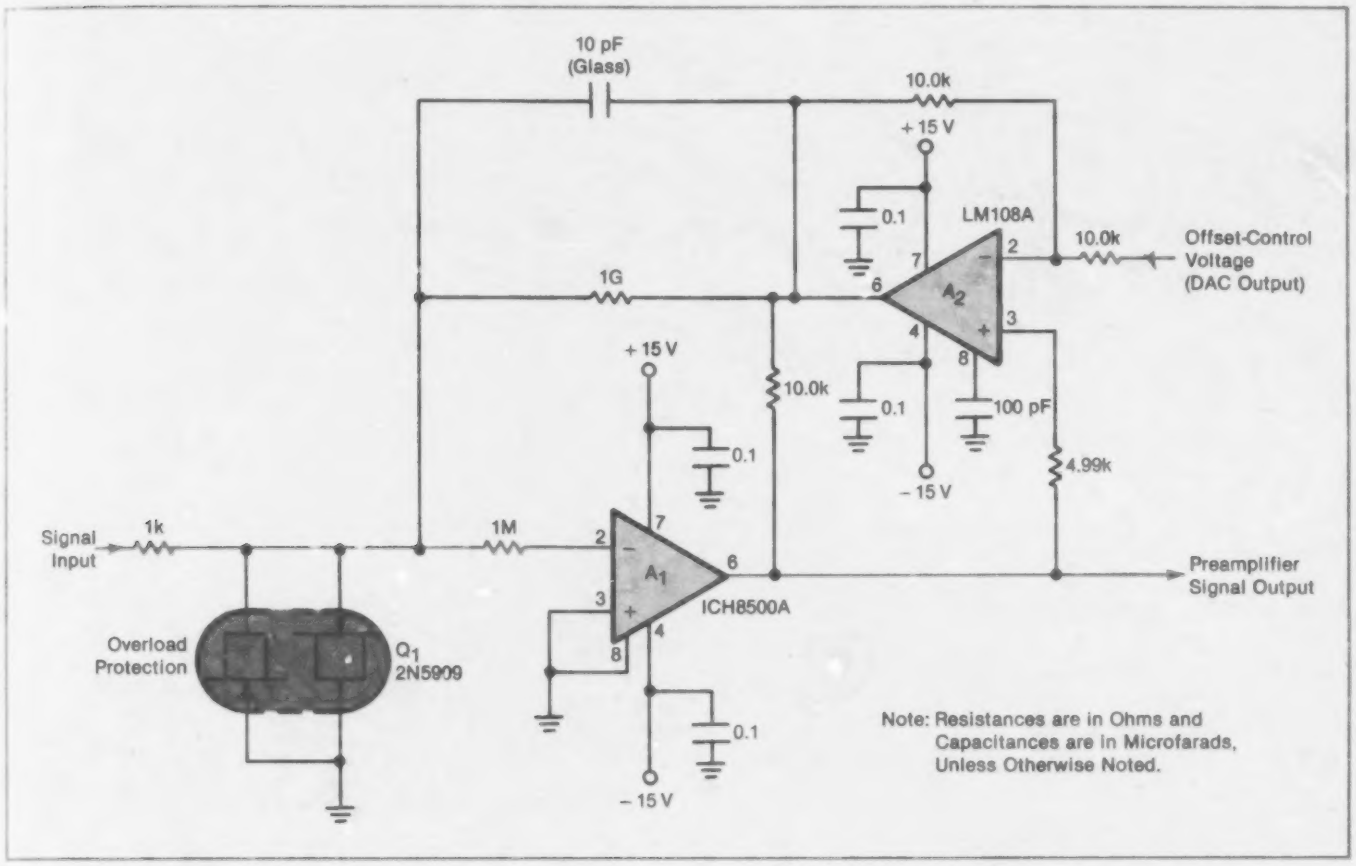
Figure 2. The **Energy Levels of the Ge_xSi_{1-x}/Si Superlattice** are shown here with an applied electric field. Photons of energy greater than ΔE(x) excite holes from the valence band of Ge_xSi_{1-x} to the valence band of Si. The holes are then swept to the cathode by the electric field.

Electrometer Amplifier With Overload Protection

Circuit features low noise, input offset, and high linearity.

Ames Research Center, Moffett Field, California

A prototype dc amplifier designed for use with an ion detector has features that are desirable in general laboratory and field instrumentation. The circuit is assembled from commercially available integrated circuits.



The **Input Preamplifier** includes input-overload protection and a nulling circuit to subtract a dc offset from the output.

The critical part of the circuit is the preamplifier (see figure), which is basically a current amplifier. The current is fed to the inverting input of operational amplifier A_1. The feedback loop keeps the input resistance low, maintaining the input voltage within millivolts of ground.

The preamplifier is protected from excessive input signals of either polarity by the 2N5909 junction field-effect transistor (JFET). While a pair of anti-parallel-connected diodes might suffice in a less sensitive application, the JFET is used here because it is a low-leakage, low-capacitance unit. With the millivolt normal input levels, leakage through the JFET is not significant.

A nulling circuit makes it possible to set the preamplifier output voltage to zero at a fixed low level (up to $\pm 10^{-8}$ A) of the input current. (This level is called the standing current and corresponds to the zero-signal level of the instrumentation.) The opposing (offset) current is generated in the 10^9-Ω feedback resistor to buck the standing current.

The offset current is set by thumbwheel-switch control inputs to a digital-to-analog converter (DAC). The DAC output is subtracted in A_2 from the signal output, and the difference signal at the output of A_2 is the voltage that develops the bucking current. This somewhat complex nulling arrangement produces less shot noise than would be produced by simply feeding a bucking current directly to the preamplifier input.

Different current ranges are reached by feeding the preamplifier output to low- and high-gain amplifier chains. To reduce noise, each chain includes a 1.5-Hz corner active filter. The amplifier operates with a linear output over the range of ±10 V for input signals ranging from $\pm 10^{-13}$ to $\pm 10^{-8}$ A. The total noise generated in the circut is equivalent to an rms input-current variation of about 10^{-3} A.

This work was done by Fritz H. Woeller of **Ames Research Center** *and R. M. Alexander of TRW, Inc. For further information, Circle 44 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11457.

Semiconductor Laser With Two-Dimensional Beam Steering

An added electrode provides steering in a second direction.

NASA's Jet Propulsion Laboratory, Pasadena, California

The proposed modification of a monolithic semiconductor injection laser capable of one-dimensional electronic beam steering should enable the deflection of the beam in a second direction. Such a laser chip could provide beam pointing or raster scanning for applications in optical communications, data processing, image scanning, and optical ranging.

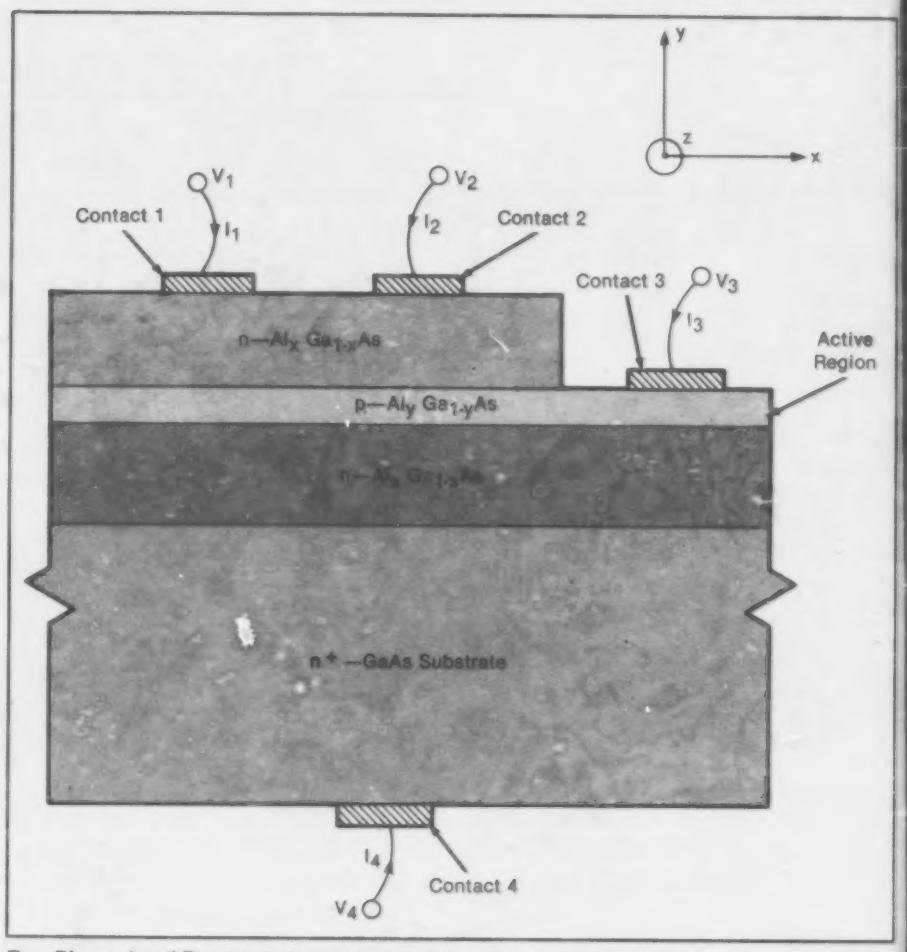
To deflect the laser beam in a given plane, the charge density in the active region that emits the light must have a gradient in that plane along the direction perpendicular to the emitted light. Deflection occurs because the charge gradient

affects the waveguide properties of the laser. The proposed laser geometry shown in the figure should provide control of such gradients in two perpendicular directions.

Conceptually, the four-terminal device is a combination of an npn transistor and a laser fabricated in AlGaAs. (It could also be fabricated in such other atomic systems as GaAsP.) As in the existing version of this device, the beam is scanned in the x-z plane by variation of the ratio or of the magnitudes of I_1 and I_2 (or of $V_1 - V_4$ and $V_2 - V_4$). However, the addition of electrode 3 to the transistor base region should enable the control of the vertical charge distribution, which affects the beam axis in the y-z plane.

The amount of beam steering achievable would be determined experimentally. In the one-dimensional case, beams have been steered by ±2 beam widths in the x-y plane. There is a tradeoff between the amount of steering in the y-z plane and the laser threshold current. For large beam deflections, the active region must be relatively thick (at least 1 μm) and must have an aluminum content similar to that in the cladding layers.

This work was done by Joseph Katz of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 77 on the TSP Request Card.*
NPO-16031



Two-Dimensional Electronic Steering of the beam from a proposed semiconductor injection laser would be achieved by adding electrode 3 to a laser that was previously capable of one-dimensional beam steering. The laser beam would come out of the page in the z direction from the p-type base region.

MOSFET Power Controller

High current and voltage are controlled remotely.

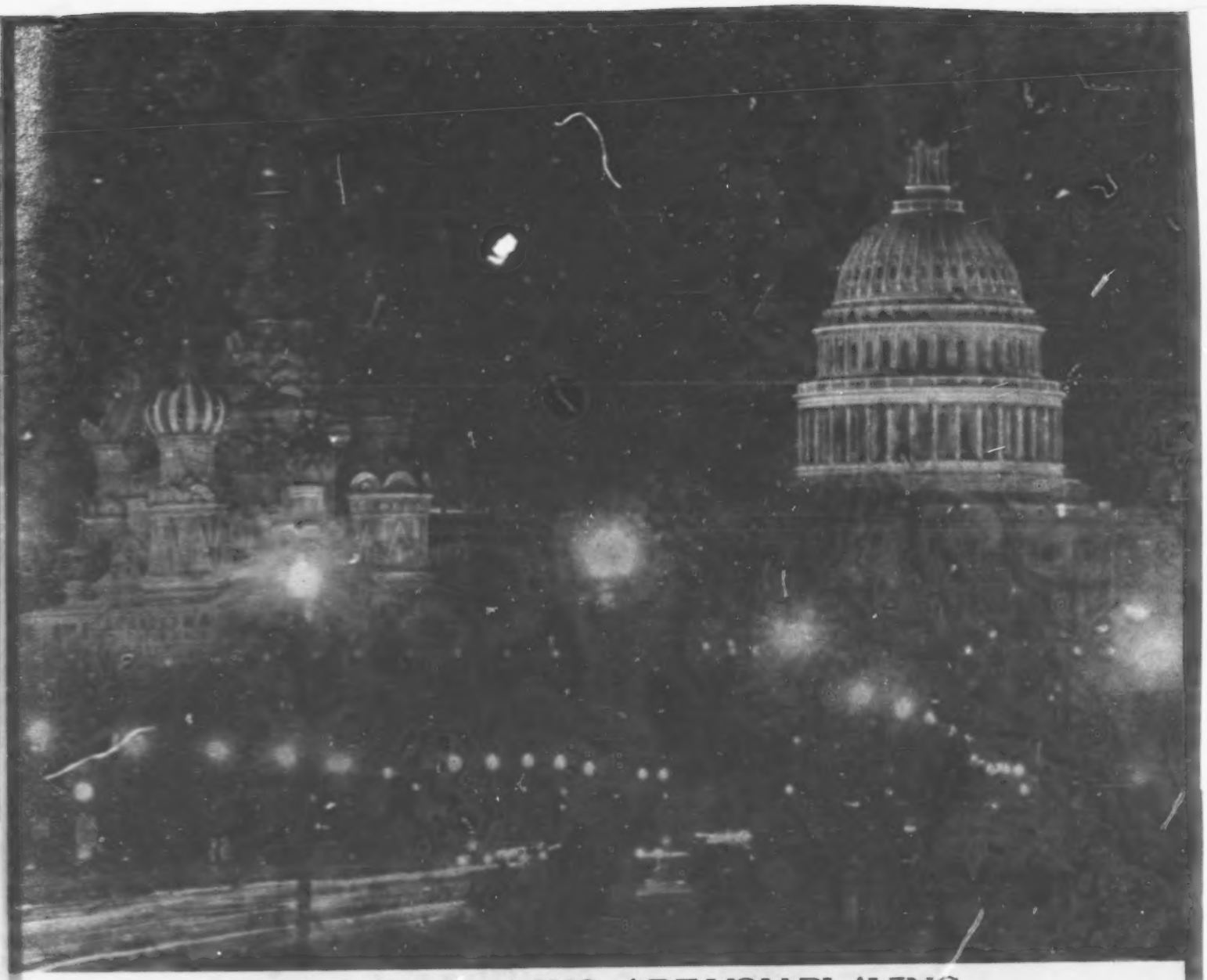
Lewis Research Center, Cleveland, Ohio

The availability of high-voltage MOSFET's that have low "on" resistance is the enabling factor in developing improved remote power controllers (RPC's). To demonstrate the capabilities of these devices, they were used to build an RPC that would withstand 1,000 V and switch 25 Adc. One of the unique features of this RPC (see figure) is that it uses two banks of parallel-connected MOSFET's in series to provide the required voltage capability. It also has an improved trip circuit.

To insure voltage sharing between the switch banks, low-impedance, gate-drive circuits were used that provided a controlled range for turn on. They are individually trimmable to insure simultaneous switching within a few nanoseconds during both turn on and turn off. The control circuit for each switch bank and the overcurrent trip circuit float independently and are supplied power via transformer T_1 from an inverter. Control of the floating stages is by optocouplers.

At turn on, optocouplers OC_1 are on, clamping pin 2 of U_{102} and pin 3 of U_{101} to the negative rail. This keeps Q_{101} turned off and $Q_{102A\text{-}D}$ conducting. Therefore, power switch $Q_{104A\text{-}J}$ is open. After a delay of 25 ms, OC_1 is turned off, pin 2 of U_{102} is driven high, and $Q_{102A\text{-}D}$ releases the gate circuit of $Q_{104A\text{-}J}$. Pin 3 of U_{101} goes high, generating a controlled ramp to turn $Q_{104A\text{-}J}$ on. The rate of rise of the ramp is controlled by C_{101}. Turn off reverses this process. $Q_{102A\text{-}D}$ is turned on as described above, turning off the 10 parallel MOSFET's, $Q_{104A\text{-}J}$. This can be done in one-half μs. Normal overcurrent tripping with an inverse time delay uses operational amplifiers U_{303A}, U_{303B}, and associated components.

CR_{303} is a 1.22-V precision voltage reference that provides a bias current that subtracts the load-current signal from R_{SH} and R_{306} at the noninverting input of pin 2 of V_{303A}. For normal load current, the R_{305} bias current exceeds the R_{306} load-current signal, and the output voltage of V_{303A}, pin 1 will be at a low level. At high values of load current, C_{302} will be charged through resistor R_{303}. The capacitor integrates the input current above 1.2 per unit, and the voltage at pin 1 of U_{303A} continues to rise until the voltage at pin 5 of U_{303B} reaches 1.22 V. Thus, when the output voltage of the integrator (pin 1



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Circle Reader Action No. 353

of $U_{303A\text{-}O}$) exceeds 1.22 V, pin 7 of U_{303B} goes high, firing SCR_{301}, and causing conduction of OC_3. An amplifier not shown on the figure boosts the OC_3 signal and turns on OC_1. R_{303} is included in the integrating circuit to lower the trip time at higher currents, since the integrating current causes a voltage drop in R_{303}. Thus the voltage on pin 1 of U_{303A} could rise rapidly since some of the voltage would appear across R_{303}. R_{303} is chosen to give instant tripping if the current exceeds three per unit.

A second, faster acting circuit is used for fault protection. It responds only to steep current fronts by sensing a high di/dt developed across the shunt. C_{303} can be considered a short circuit for these rapidly changing currents, which allow V_{SH} to appear across R_{310} and R_{311} in series. Since these resistors are equal, one-half of V_{SH} appears at U_{302}. The polarity of this voltage is negative, and since it is applied to the inverting input of U_{302}, will be driven positive and fire SCR_{301}, which turns on OC_3. Since response to small changes is not desired, a positive voltage is established at pin 3 of U_{302} by CR_{303}, R_{309}, and R_{310}. This positive reference voltage must be overcome by the negative V_{SH} voltage to drive pin 3 of U_{302} negative. Because this positive reference voltage is controlled on pin 3 of U_{302}, the circuit can be made to respond to transient currents of any magnitude. U_{301} is used to modify this reference voltage proportionally to the load current. This enables a smaller change in current to trip the circuit when the steady-state current is near full load.

This work was done by J. T. Mitchell and K. Jones of Westinghouse Electric Corp. for **Lewis Research Center.** *Further information may be found in NASA CR-168041 [N83-21236/NSP], "Kilovolt dc Solid State Remote Power Controller Development."*

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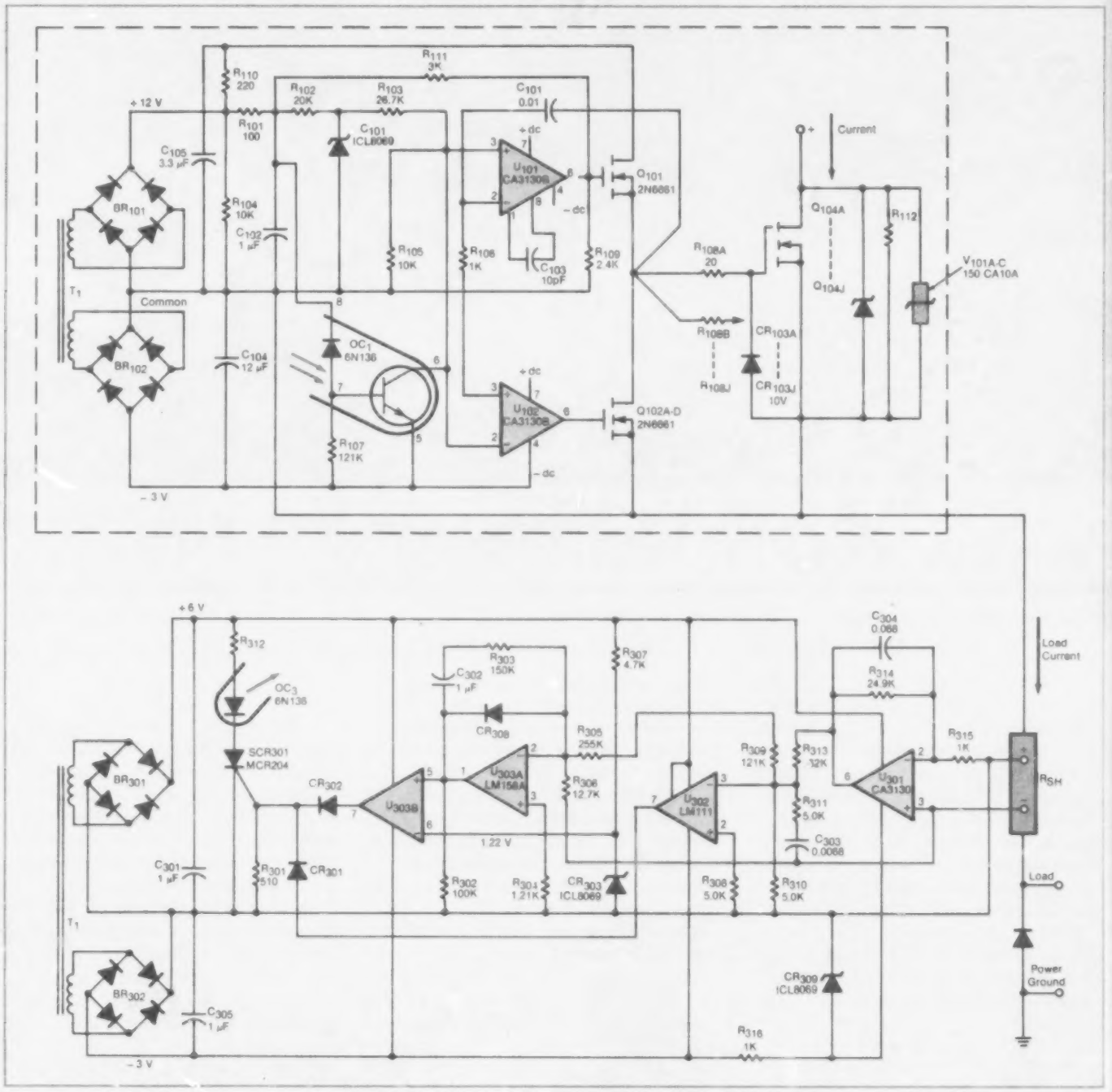

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Lewis Research Center, Cleveland, Ohio

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- No contact bounce or wear and no arcing;
- Precise open and close times;
- Controlled current transients;
- Consistent, repeatable overload protection over the temperature range; and
- Immunity to high vibration and shock.

The figure shows a fast-acting base-drive circuit and a fast-acting overcurrent-protection circuit. There is also a power converter feeding T_1 and logic circuits that command the RPC on and off. These are of conventional design.

The fast-acting base-drive circuit operates as follows: During normal operation, C_{106} becomes charged because of the few volts dropped across CR_{111}, CR_{113}, and R_{114}. For a fast turnoff, SCR_2 is fired, which allows C_{106} to discharge through SCR_2, R_{116}, and R_{115}. This applies a reverse potential across Q_{101} and Q_{102} emitter/base junctions, which clears the junction of carriers for a fast turnoff.

The three diodes are included in series with R_{114} to obtain a minimum voltage of three diode drops, to work against the drop of SCR_2 and have sufficient voltage left to clear the carriers in Q_{101} and Q_{102}.

In the fast-acting overcurrent-protection circuit, Z_{101} and Z_{102} are connected in a normal inverting threshold/integrator trip circuit. Diode CR_{110} is a 1.22-V precise reference which, along with R_{110} and R_{112}, sets the threshold. At this threshold Z_{101} responds and causes output pin 6 to go high, in turn charging capacitor C_{105} through R_{109}. When the voltage at pin 6 of Z_{101} is greater than the CR_{110} reference voltage, the Z_{102} comparator output at pin 2 becomes positive, firing SCR_1 through CR_{105}. This sequence causes a "slow" trip response from the base-drive circuit, since C_{106} must discharge through CR_{106} in addition to SCR_1. The result is less reverse voltage across the emitter/base junctions of Q_{101} and Q_{102}.

Pin 6 or Z_{101} can reach the reference voltage of 1.22 V by allowing C_{105} to charge to 1.22 V (integrating the current), resulting in an inverse current/time relationship. If the load current reaches 3 per unit (PU), a highly negative voltage tends to be established at pin 2 of Z_{101}; its output pin 6 would be driven suddenly positive. The resulting voltage drop would appear across R_{109}, since C_{105} would be a short circuit. This condition would allow pin 6 to reach above 1.22 V without "waiting" for capacitor C_{105} to charge, which could result in an "instant" tripping.

Resistor R_{109} is chosen for this to occur at 3 PU. Circuits Z_{101} and Z_{102} are relatively slow; this instant tripping would take several microseconds before the output of Z_{102} becomes positive. If this occurs as the result of a short circuit, the current could be well above 5 PU before the tripping is initiated. No action would begin until the current reaches 3 PU, and in the few microseconds of response time of Z_{101} and Z_{102}, the current could be much higher. Therefore, this circuit is not adequate for short-circuit protection without current limiting but is adequate for light overloads.

The current-sensing shunt R_{117} gives a 50 mV drop at a 25 A (1 PU) load. This voltage does not normally appear at pin 3 of Z_{103} because of capacitor C_{103}. However, with a rapidly rising current (e.g., a steep front of current from a short circuit), C_{103} appears as an effective short circuit, and half of the negative shunt voltage appears at pin 3 of Z_{103} (R_{106} and R_{107} are equal and divide the shunt voltage).

Pin 3 of Z_{103} is normally held at +55 mV. Therefore, when a steep front of load current reaches 2.2 per unit, the net voltage at pin 3 of Z_{103} would be zero, since the shunt voltage of −110 mV is divided and exactly neutralizes the +55 mV at the inverting terminal. As the steep front increased beyond 2.2 PU, the output of Z_{102}, a fast operating amplifier, would go positive and fire SCR_1 and SCR_2. This would give a "fast" tripping action as previously described. The tripping action takes less than one microsecond. The remainder of the circuit consists mainly of power supply and logic.

This work was done by P. Hower of Westinghouse Electric Corp. for **Lewis Research Center**. *Further information may be found in NASA CR-168041 [N83-21236/NSP], "Kilovolt DC Solid State Remote Power Controller Development."*

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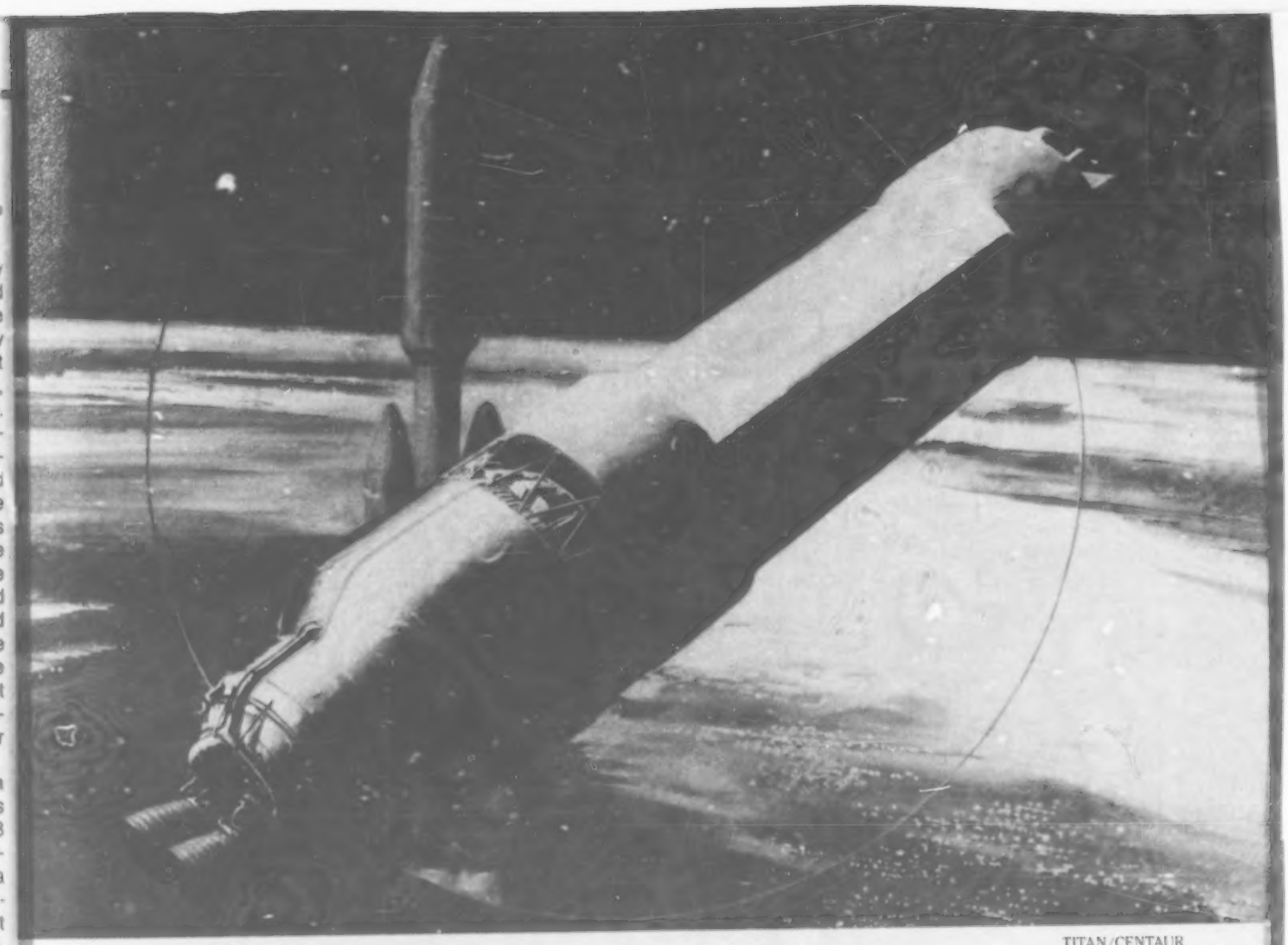

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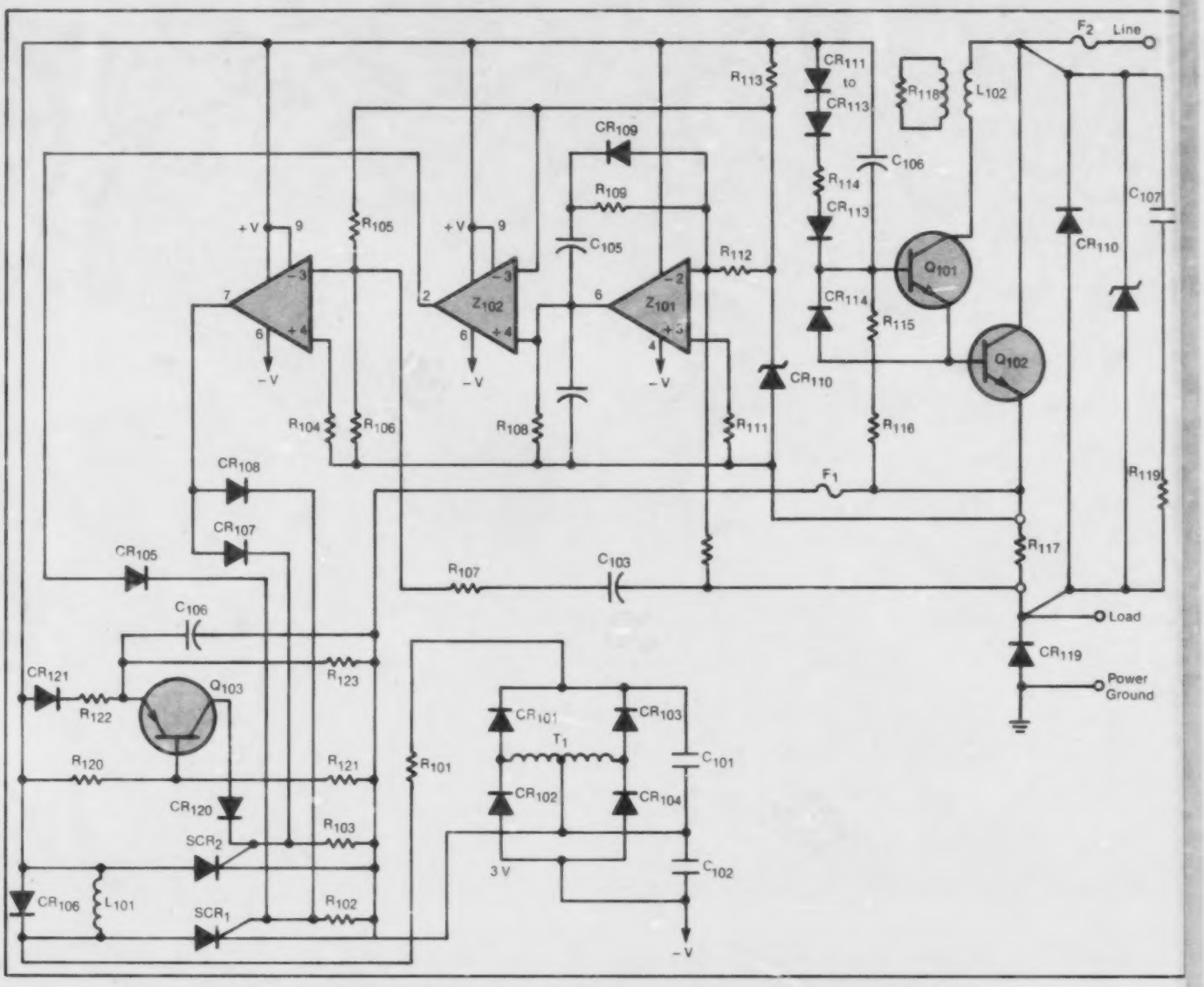

The **Base-Drive and Overcurrent-Protection Circuits** respond rapidly to overcurrent conditions.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

List of Preferred Electronic Parts

Components that have passed stringent qualification tests are tabulated and described.

A preferred parts list tabulates electronic, magnetic, and electromechanical parts for electronic equipment in which reliability is a major consideration. The list presents parts that have qualified for service in critical flight and ground-support applications by NASA's Jet Propulsion Laboratory.

Destructive and nondestructive qualification testing confirmed that the parts are capable of withstanding spacecraft environments without excessive degradation and have stable characteristics during their operating lives. Testing also assessed the effects of electrical, environmental, and mechanical stresses in various levels and time durations.

Each part on this list must undergo a design appraisal in which device construction and processing are examined. This examination provides guidance in the design of screening tests. Approval of the manufacturers' materials, processes, quality control, and engineering and production capabilities are also required for part approval.

Parts included in the list are capacitors, diodes, filters, fuses, magnetic devices, microcircuits, relays, resistors, switches, and transistors. Each category of parts is covered in a separate section. An introduction to each section contains application notes and brief descriptions of the major types of the part. The section on diodes, for example, describes the following types: General-purpose rectifiers, power rectifiers, signal or switching diodes, voltage regulators, special-purpose diodes (microwave, optical, and current-regulating), and silicon-controlled rectifiers and switches.

This work was done by Robert E. Covey, W. Richard Scott, Lawrence M. Hess, George Steffy, and Frank R. Stott of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-176258 [X86-10015/NSP], "JPL Preferred Parts List."*

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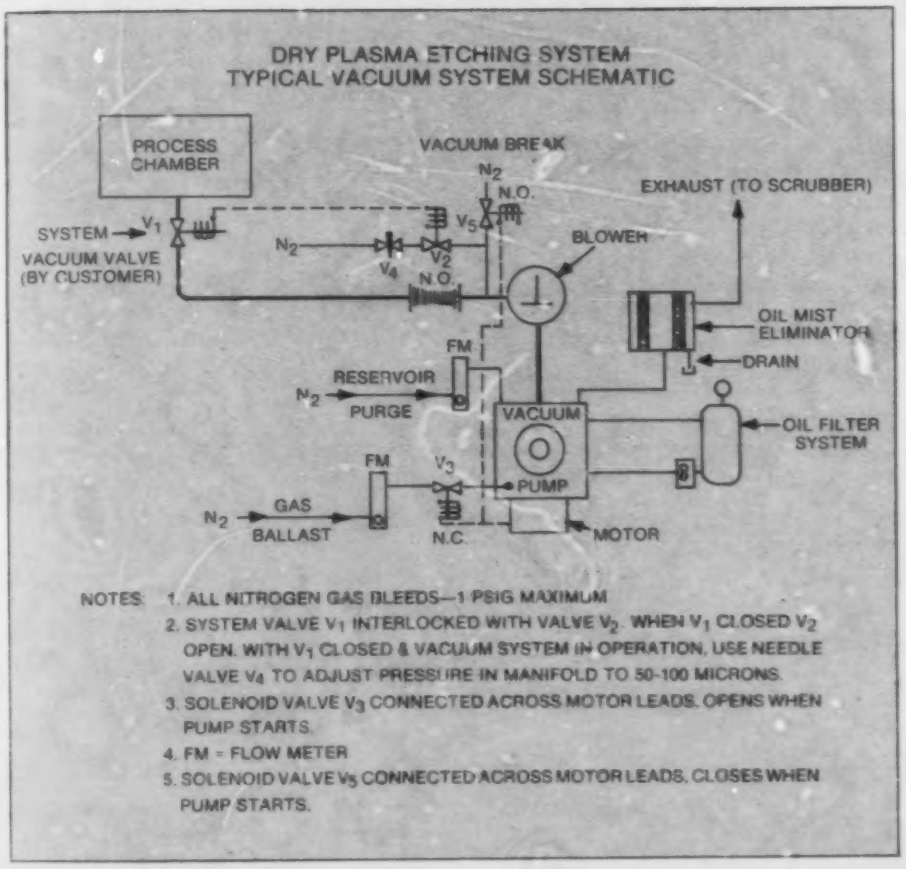
How to stop water vapor from destroying your vacuum system when you're plasma etching.



NOTES:
1. ALL NITROGEN GAS BLEEDS—1 PSIG MAXIMUM
2. SYSTEM VALVE V_1 INTERLOCKED WITH VALVE V_2. WHEN V_1 CLOSED V_2 OPEN. WITH V_1 CLOSED & VACUUM SYSTEM IN OPERATION, USE NEEDLE VALVE V_4 TO ADJUST PRESSURE IN MANIFOLD TO 50-100 MICRONS.
3. SOLENOID VALVE V_3 CONNECTED ACROSS MOTOR LEADS. OPENS WHEN PUMP STARTS.
4. FM = FLOW METER
5. SOLENOID VALVE V_5 CONNECTED ACROSS MOTOR LEADS. CLOSES WHEN PUMP STARTS.

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The following installation and operation procedures will help you keep your system operating smoothly.

The right installation.

Install PVC exhaust piping instead of galvanized or black iron pipe, and an oil mist eliminator to reduce oil loss from the pump.

The exhaust line should be installed so it can easily be disassembled for periodic cleaning and the vacuum manifold must be leak-free.

The right operation.

Operate the vacuum system continuously and make sure the vacuum pump is gas ballasted during processing with a nitrogen flow rate of 1 to 2 L/M.

Purge the reservoir with nitrogen (in humid ambients it may be necessary to increase the nitrogen flow). Do not pump on the process chamber with the vacuum system at blank-off pressure as oil backstreaming may result. When necessary to shut down the vacuum system for over 8 hours, fill gas ballast with nitrogen for at least 4 hours before stopping.

The right maintenance.

Drain the exhaust oil mist eliminator weekly. If oil is clean, it can be reused by returning to the pump. If it is "milky" or cloudy, it should be decanted before returning to pump reservoir. Cleaning interval is determined by the amounts of particulates accumulated.

Monitor differential pressure across the oil filter. Replace element when filter pressure shows a significant increase above baseline pressure. Actual pressures will be determined by your own process.

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Electronic Systems

Hardware, Techniques, and Processes

46 **Pilot-Tone System for Mobile Communications**
48 **Reduced-Bandwidth Coding for Mobile Communication**
51 **Frame-Synchronization-Assisting Module**
52 **Motor Servoloop With Optical Shaft Encoder**
53 **Digital Pseudonoise Generator**
54 **Compensating Function for Antenna Pointing**
56 **Airborne Instrumentation Computer System**
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Computer Programs

70 **Computer Program For Space-Shuttle Testing**

Pilot-Tone System for Mobile Communications

The degrading effects of multipath fading would be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

In a proposed mobile communication system called the tone-calibrated technique, a pilot tone provides a phase- and amplitude-calibration reference to enable the coherent demodulation of the signal at the receiver despite fading. The signal received by or from a mobile terminal is severely and rapidly faded due to the motion of the terminal and the propagation of the signal along multiple paths. This fading introduces random amplitude modulation and phase modulation with a bandwidth of twice the Doppler frequency shift.

Under these conditions, it is difficult to extract the carrier from the faded sidebands for use in demodulation. However, if a pilot tone is transmitted along with the rest of the signal, it undergoes the same fading, maintaining the same amplitude and phase relationship with the rest of the signal at the receiver that it had at the transmitter. Thus, it can serve as the carrier reference for demodulation.

The tone-calibrated technique is intended for use with phase-modulated data or telephony systems using Manchester digital pulse-code modulation. Because this kind of modulation has no spectral component at zero frequency, there is a null at the carrier frequency in the middle of the spectrum occupied by the transmitted signal; that is, the transmitted signal is all sidebands and no carrier. The

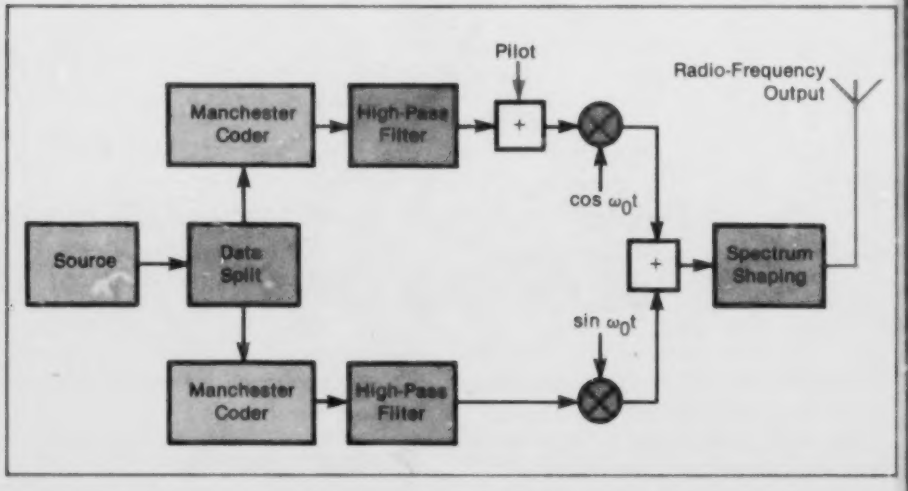

Figure 1. **In the Transmitter,** a Manchester digital pulse code is first high-pass filtered, then used to modulate a carrier. A pilot tone is inserted at the transmitter to provide a fade-compensating calibration tone at the receiver.

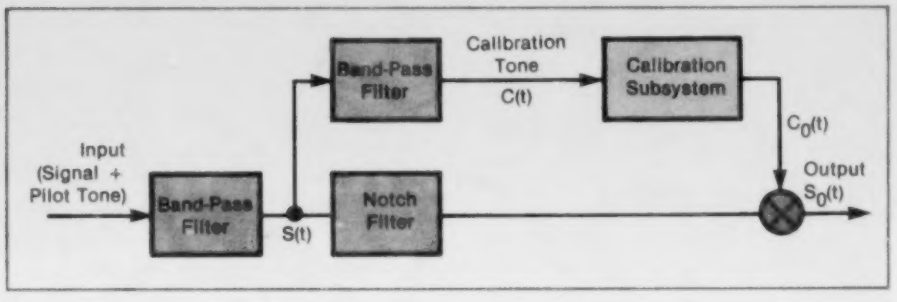

Figure 2. **In the Receiver,** the faded pilot tone is extracted for use in the coherent demodulation of the signal. The faded pilot divided by its amplitude squared is mixed with the faded signal to recover unfaded Manchester pulses.

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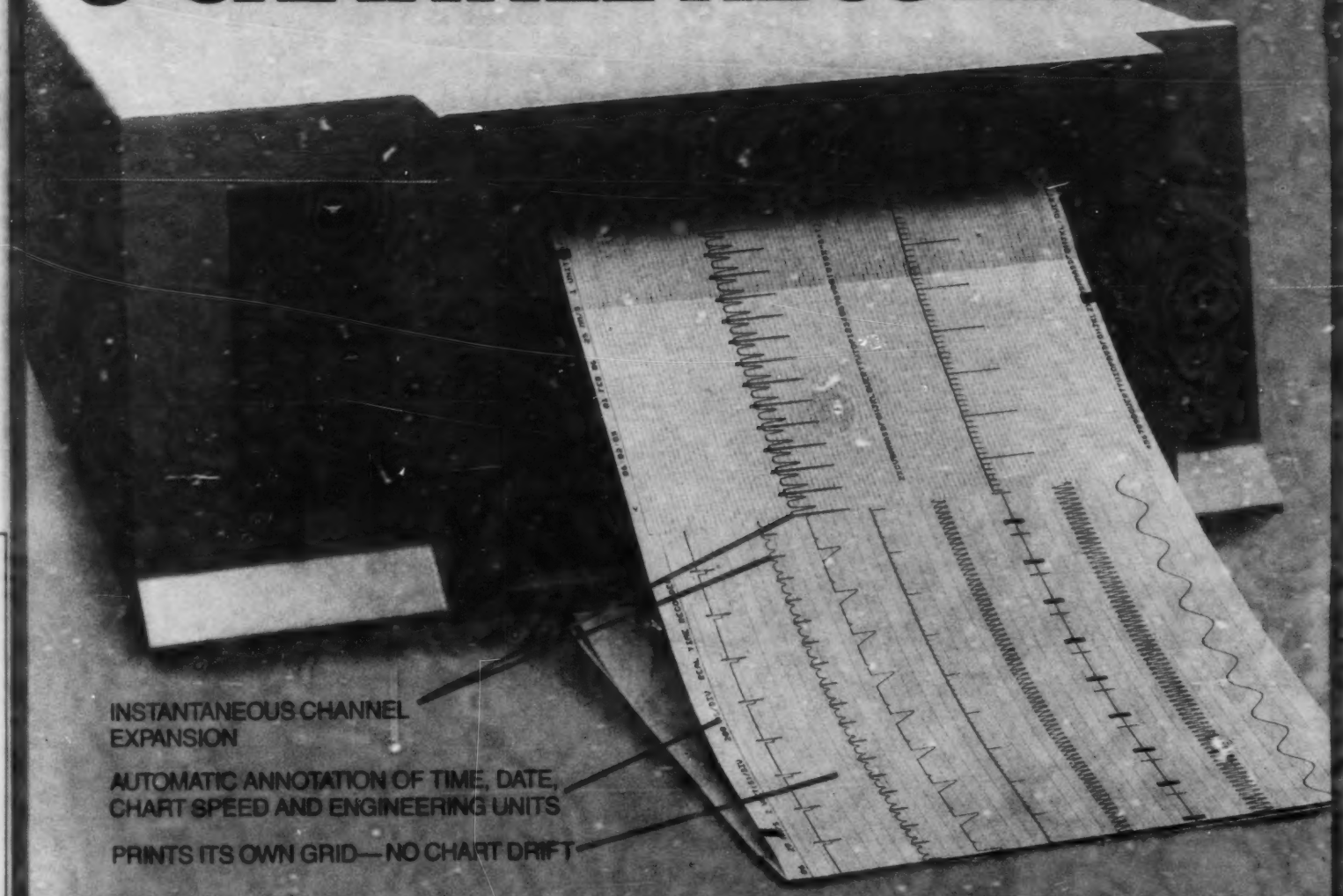

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pilot tone is conveniently inserted at the null frequency and consists of nothing more than a low-power replica of the normally absent carrier.

The low spectral density of the modulation at and near zero frequency makes it possible to suppress the low-frequency components with little adverse effect on the transmission of data. Taking advantage of this, the modulation is fed through a filter (see Figure 1) that passes frequencies above twice the expected Doppler shift. The central null in the transmitted signal is thereby broadened to provide more spectral room for the insertion of the pilot tone. At the receiver, this facilitates the acquisition of the carrier information without interference from the sidebands.

In one branch of the receiver (see Figure 2), the input signal plus pilot tone is notch-filtered to extract the signal. In another branch, the same input is bandpass filtered to strip off the signal and obtain the faded pilot tone. The calibration subsystem divides the faded pilot tone by its estimated amplitude squared, yielding the calibration tone. This calibration tone is mixed with the signal to recover a fade-compensated version of the original modulating signal.

This work was done by Faramaz Davarian of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 25 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office — JPL [see page 29]. Refer to NPO-16414.

Reduced-Bandwidth Coding for Mobile Communication

Fade-resistant mobile systems would use power and spectrum more efficiently.

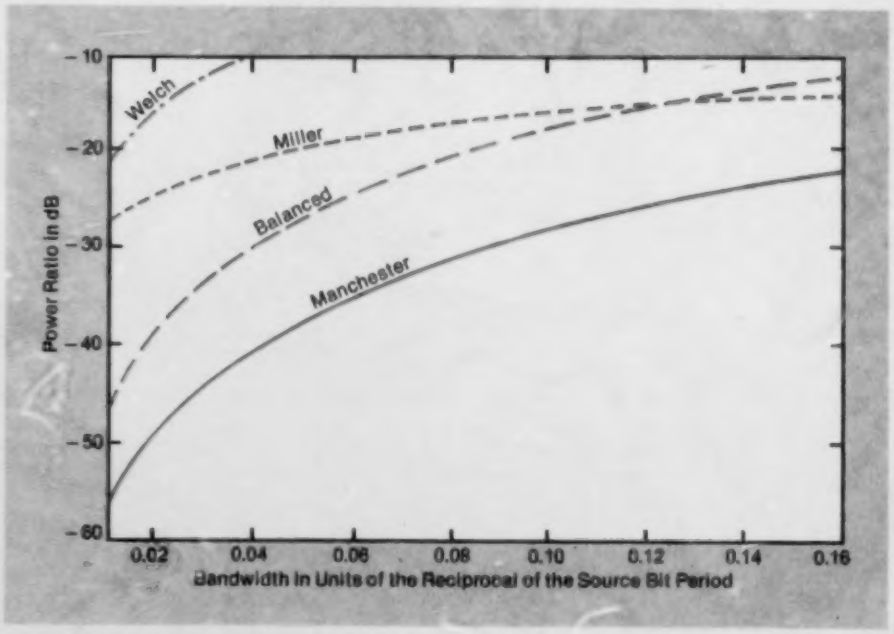
NASA's Jet Propulsion Laboratory, Pasadena, California

Balanced coding, an efficient, new digital-coding technique, would reduce the bandwidth and power requirements of mobile communications that use satellite repeaters. The coding technique, intended for a residual-carrier transmission system, would alleviate the fading and spectrum crowding that hamper mobile communications.

The proposed transmission system employs the tone-calibrated technique (TCT). A residual carrier is used in this technique to reduce fading-induced effects and coherently demodulate the received signal. The TCT is potentially efficient in its use of power and of the frequency spectrum.

However, the success of the TCT in reaching its power and bandwidth objectives depends on the way in which the baseband signal is encoded. Because the residual carrier power should not be larger than the minimum power necessary for effective reception, the received tone (the "tone" being the residual carrier) must be free from data-induced interference (self-interference). Therefore, the code should be one that results in a null in the modulation spectrum near zero frequency. Because multipath fading causes the tone to spread in frequency by as much as twice the Doppler frequency, the code must ensure low power density up to the maximum expected Doppler shift. On the other hand, overbroadening should be avoided because it results in gross expansion of the transmission band.

The balanced code gives the requisite low-power band around zero frequency without overbroadening the transmitted signal spectrum. A balanced code contains an equal number of ones and zeros in a word. This characteristic guarantees a spectral null at dc regardless of the code length. The code is constructed by mapping every group of M source symbols into a greater number, N, of channel symbols, N being the number of symbols in a word.



The Portion of the Total Power contained within the frequency band from zero to the indicated frequency is plotted for four codes. While the Manchester code has the lowest spectral power density near zero, the balanced code results in less bandwidth expansion at the overall signal.

Of the known codes, the Manchester code (N = 2) gives the lowest spectral density near zero frequency (see figure) but also results in a doubling of the signal bandwidth. For example, for a channel with a maximum Doppler rate of 78 Hz, the Manchester code is the one of choice for a source rate of 1,200 bits per second. The balanced code with N = 6 multiplies the bandwidth by 1½ and outperforms the Manchester code at rates beyond 2,400 bits per second. Although balanced coding adds a small amount of delay to the modulator and requires a slightly more complicated receiver, these are minor disadvantages.

This work was done by Faramaz Davarian of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 26 on the TSP Request Card.*

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Circle Reader Action No. 435

Frame-Synchronization-Assisting Module

The main processor is relieved of preliminary computational tasks.

NASA's Jet Propulsion Laboratory, Pasadena, California

An auxiliary data processor does computations related to the synchronization of frames of telemetry data, thereby relieving the main processor of this task. The auxiliary processor, called a frame-synchronization-assisting module (FSAM) sorts through large amounts of data to determine whether they are valid and, if so, how they are configured.

The FSAM searches any data passed to it for four possible types of frame-synchronizing codes. These include the following:

1. True forward (normal bit polarity and order);
2. Complement forward (inverted bit polarity);
3. True reverse (normal bit polarity, reverse bit order); and
4. Complement reverse (inverted bit polarity and order).

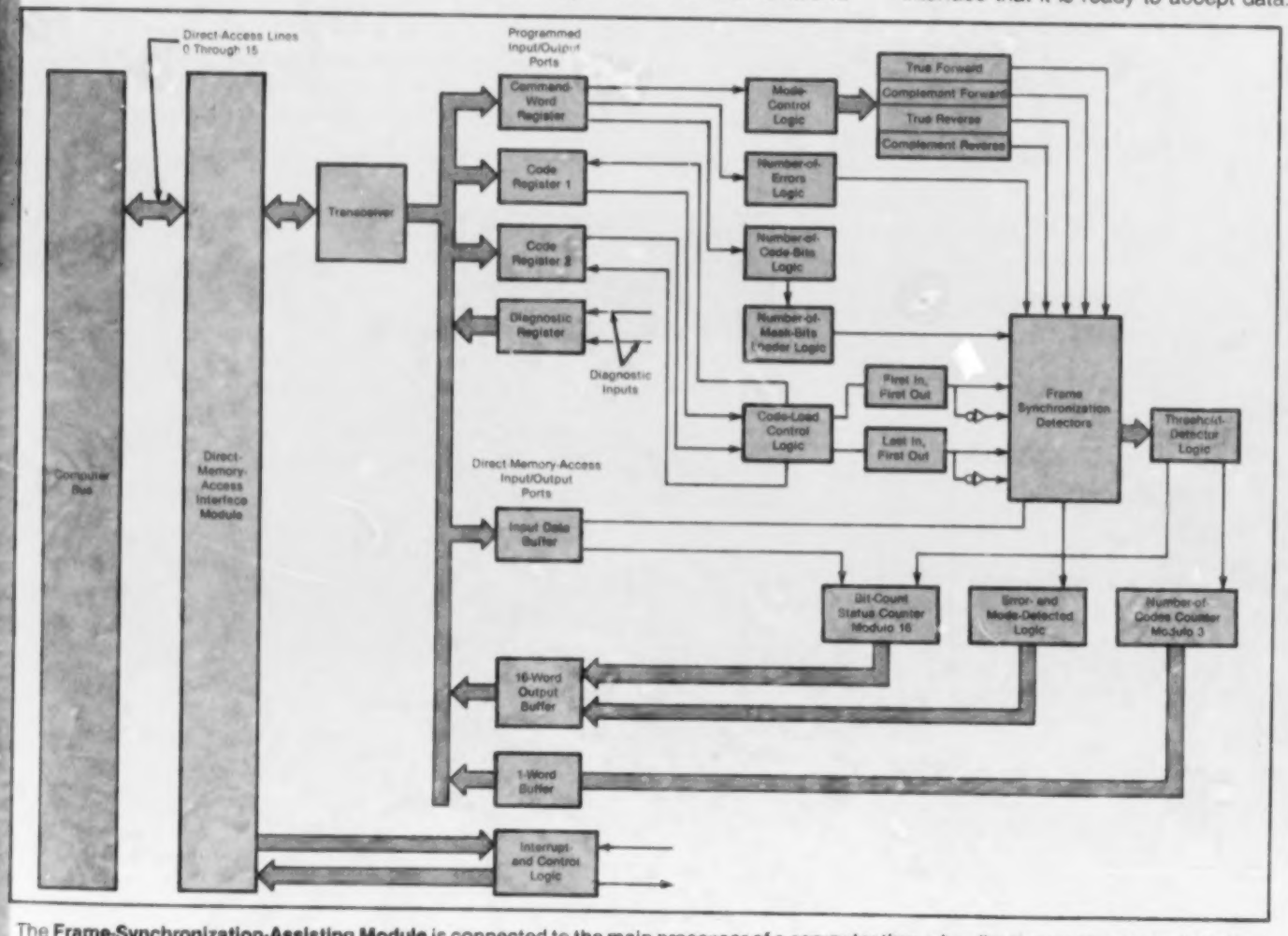
The FSAM reports back to the main processor with a 17-word result block. The first 16 words contain relative bit locations of the detected codes, with mode and error information. The 17th word indicates the number (up to eight) of codes that were detected, thereby enabling the user to go directly to word 17 to determine whether a valid correlation has occurred, without having to peruse the first 16 words.

In principle, any number of data may be passed to the FSAM. In practice, the number is determined partly by the user's confidence in finding the desired codes in a data block and partly by the limitations of the interface/host processor. In the present design, a block contains 4K words.

As shown in the figure, all interface and data signals between the FSAM and the main processor pass through the direct-memory-access (DMA) module, which lies directly on the computer bus. The DMA module acts as an interface for all DMA functions and programmed input/output communication with the bus.

Operation begins when the command-word register is loaded under programmed input/output. The command word specifies the type of code, the number of bits in the code, and the allowable errors. Any combination of the four code modes may be selected to conduct a code search. Next, the actual image in memory of the desired code is passed under programmed input/output in two words.

After the three words are loaded, the FSAM automatically sets up to look at incoming data and signals the user via the interface that it is ready to accept data.



The **Frame-Synchronization-Assisting Module** is connected to the main processor of a computer through a direct-memory-access (interface) module. It examines data in the computer memory to find frame-synchronizing codes.

The data are then passed to the FSAM until the desired number of words has been counted by the word counter in the DMA module. At this point, the module sends a signal that turns off the code-detection function of the FSAM. Under interrupt control, the FSAM indicates, to the user's program, that it is ready to pass the 17-word result block. This completes one cycle, and the FSAM is ready for the next three command words.

This work was done by Carl DeSilveira of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 33 on the TSP Request Card.*
NPO-16564

Motor Servoloop With Optical Shaft Encoder

Position and rate feedback signals are derived from a single transducer.

Ames Research Center, Moffett Field, California

A motor control circuit derives shaft-angle and rotation-rate signals from an optical detector. The hybrid digital and analog circuit requires only a few components and has no moving parts.

A simplified block diagram is shown in the figure. The encoder includes an optical detector that emits pulses on lines A and B at intervals of 0.72° (500 pulses per complete revolution). The pulses occur when holes on the encoder disk pass by as the shaft turns. The relative phases of A and B depend upon the sense of rotation: If the shaft rotates clockwise, pulse A occurs before pulse B. The opposite is true for counterclockwise rotation.

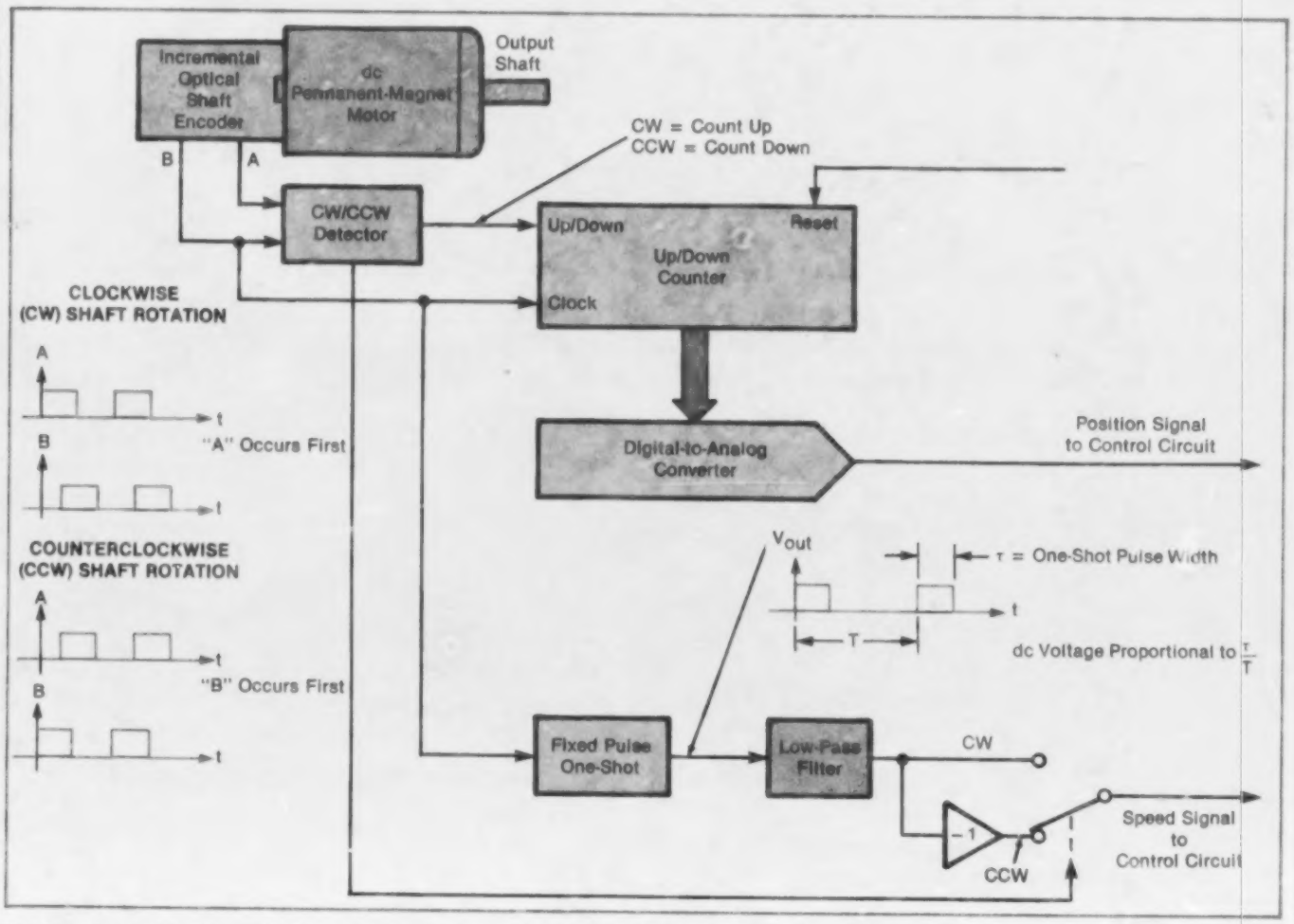
The pulses are fed to an up/down counter, which counts them up or down when the rotation is clockwise or counterclockwise, respectively. The output of the counter is fed to a digital-to-analog converter. The converter output is a voltage proportional to the shaft rotation from the angle at which the counter was last reset.

The encoder pulses are also fed to a fixed-pulse-width one shot, thereby producing a pulse train with a frequency proportional to the motor speed. After low-pass filtering, the pulse train becomes a dc voltage proportional to the motor speed.

The analog position and speed signals are fed to an error amplifier along with the position-command voltage. The amplifier output is an error signal that drives the motor in the direction that reduces the error.

This work was done by Steven P. Marascalco of Sperry Rand Corp. for **Ames Research Center**. *For further information, Circle 11 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11582.



The **Servoloop** generates digital and analog shaft-position and analog shaft-speed signals from the output of an incremental optical encoder. These signals are used in the feedback control of the motor.

Digital Pseudonoise Generator

Numbers would be generated to satisfy a probability distribution.

NASA's Jet Propulsion Laboratory, Pasadena, California

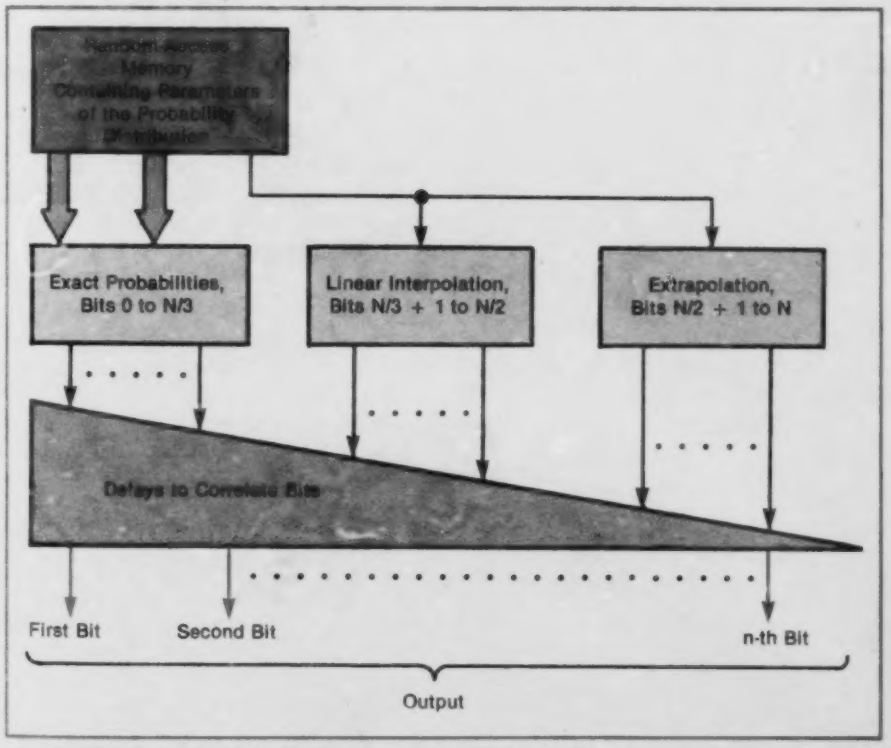
An architecture has been developed for a noise generator based on a pseudorandom number sequence. The concept involves no additions or multiplications; rather, the outputs of a set of feedback shift registers would be combined, bit-by-bit, in accordance with the desired probability distribution. The digital, pseudorandom number output could be fed to a digital-to-analog converter to generate a pseudonoise signal suitable for testing broadband amplifiers.

The output number lies between 0 and 1 and is generated in binary form with N bits. Each less significant bit depends partly on the more significant bits according to conditional probabilities for zeros and ones that satisfy the probability distribution. A binary feedback shift register associated with each bit generates a sequence of zeros and ones. The registers are initialized from values stored in a read-only memory to be linearly independent and appreciably different: This guarantees the quasistatistical independence of the N sequences.

The N shift registers are grouped into three sections (see figure). The exact section includes units that generate the N/3 (or other arbitrarily designated number) most significant bits. Each unit contains a shift-register generator of a uniform random sequence, a logic network, data lines from a random-access memory, and an address line to the memory. The last few stages of each feedback shift register feed into a logic array to get the right proportion of zeros and ones for the specified probability distribution.

In the interpolation section, each unit includes three shift registers for averaging pairs of distributions to obtain approximations of the middle bits. The first N/3 bits, already generated exactly, address the random-access memory through a control that determines the two adjacent conditional probabilities, which can be linearly combined to yield bits (N/3) + 1 through N/2.

The extrapolation section generates the N/2 least significant bits. It is similar to the interpolation section, except that only one parameter is needed in each unit. The frequencies of the least significant


Random-Access Memory Containing Parameters of the Probability Distribution
Exact Probabilities, Bits 0 to N/3
Linear Interpolation, Bits N/3 + 1 to N/2
Extrapolation, Bits N/2 + 1 to N
Delays to Correlate Bits
First Bit
Second Bit
n-th Bit
Output

The **Pseudorandom Number Generator** would generate N-bit binary numbers. Three groups of feedback shift registers interconnected according to different schemes, would generate three bit sequences to be combined into the N-bit number sequence. The delays at the output end are necessary for the correlations of the less significant bits with the more significant bits, upon which they partly depend.

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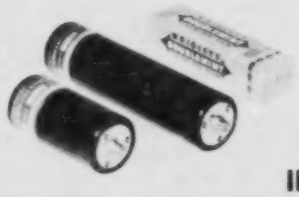

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bits are shaped from the frequencies of the earlier bits by what amounts, in effect, to an extrapolation of the distribution function.

Because the later bits depend on the earlier ones, there must be delays between the first registers to align the output bits in time. This is only an initial delay: Once the system is in full operation, pseudorandom numbers are produced rapidly, one after another.

The system is to be constructed of complementary metal-oxide semiconductor circuitry. A conceptual system using somewhat fewer than 40,000 transistors would generate 25×10^6 random numbers per second, each containing 22 bits. The error (that is, the deviation from a truly random sequence in the desired probability distribution) would be less than 2^{-22}.

This work was done by Arthur Knoebel of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 18 on the TSP Request Card.*
NPO-16627

Compensating Function for Antenna Pointing

The mean-square errors of the antenna surface are reduced.

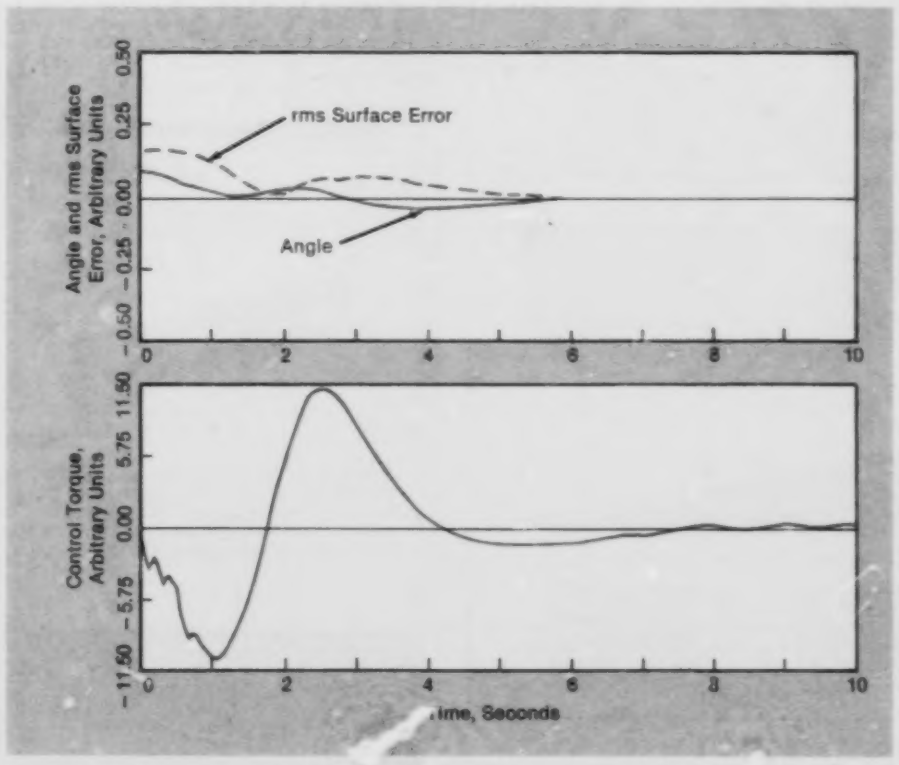
NASA's Jet Propulsion Laboratory, Pasadena, California

A compensating function helps to point a deformable antenna without inducing excessive pointing oscillations or deformations of the reflecting surface. When implemented on a computer in real time, the function enables the calculation of control signals in response to several sensor inputs: The function is devised so that the signals control the torque actuator of the antenna-pointing mechanism in such a way as to reduce or minimize the squares of the errors of the antenna surface over a long time.

The function was developed for an axisymmetric dish antenna made of mesh supported by ribs. The function is obtained by minimizing a performance index, J, given by

$$J = \int_0^\infty [q_1\Theta^2 + q_2\dot{\Theta}^2 + q_3\iint W^2 dA + ru^2]dt$$

where t = time, Θ = the angle of rigid-body-rotation error, $\dot{\Theta}$ = rotational speed, W = the displacement of the mesh reflecting surface from the position in which the rigid-body rotation and all elastic deformations are zero, dA = the increment of mesh area (the area integral is taken over the entire mesh), and u = the control torque.



The **Antenna Settles Down** toward zero surface and pointing errors and zero control torque after the imposition of an initial rotation error. The compensating function for this case is derived from a performance index that penalizes the mean-square surface error and the control torque but not the angular overshoot.

The weighting coefficients q_1, q_2, q_3, and r are chosen according to the amounts by which each error is to be mathematically penalized or minimized in the control function. The mean-square surface error weighted by q_3 is the primary term to be minimized, but the minimization of the response time and of the overshoot of the rigid-body angle are also secondary objectives. The combination of weighting coefficients that best achieves these objectives is found by numerical experimentation with the equations that describe a particular system.

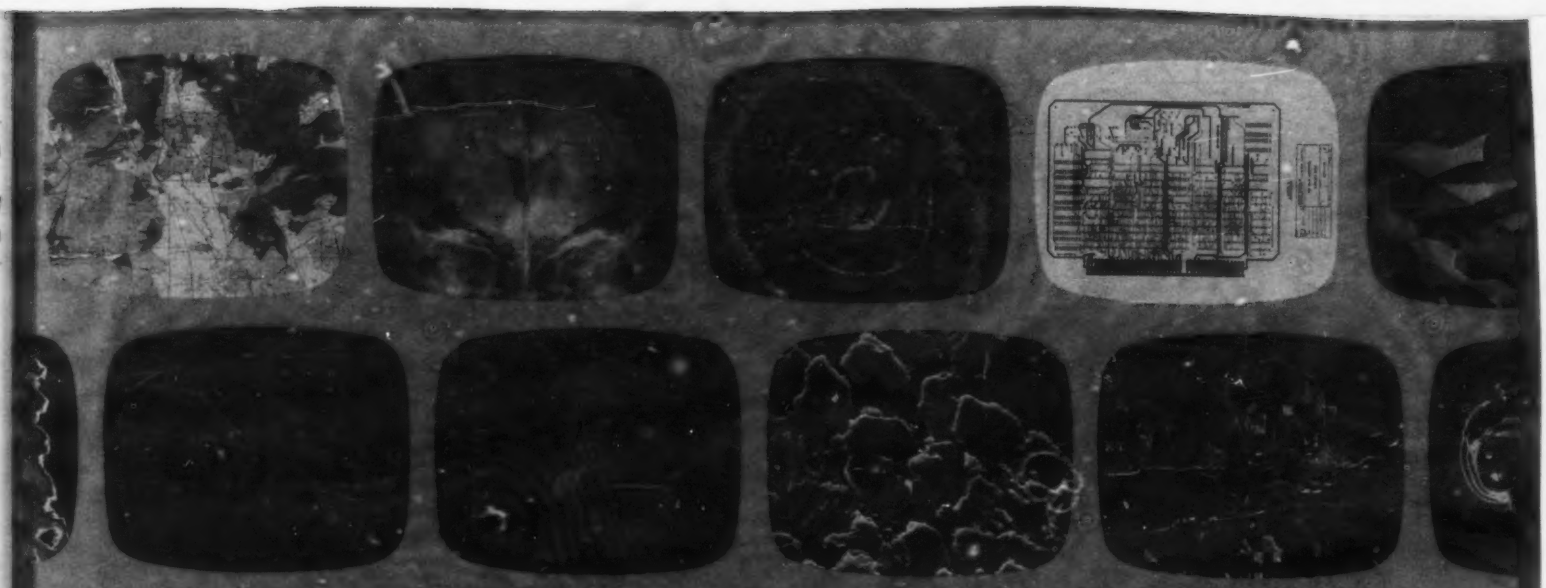
Once the weighting coefficients are found, the compensating function, F, is expressed by a matrix equation

$$F = K_n[SI - A_n + B_nK_n + G_nC_n]^{-1}G_n$$

where the subscript n denotes an *n*th order approximation, S = the Laplace-transform complex-frequency variable, I = the identity matrix, K = the control gain, G = the estimator gain, A = the antenna dynamical matrix, B = the control-input matrix, and C = the measurement matrix.

Numerical simulations have been performed for a compensating function having three channels: Channel 1 is from the hub-rotation sensor to the torque actuator. Channels 2 and 3 are from two rib-tip displacement sensors to the torque actuator; these channels have identical transfer functions by virtue of the antenna symmetry. The figure gives results from one of the simulations, showing the responses of the rigid-body error angle, the mean-square surface error, and the control torque as they evolve from an initial rigid-body-rotation error.

This work was done by D. Lewis Mingori and James S. Gibson of the University of California, Los Angeles for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 53 on the TSP Request Card.* *NPO-16616*



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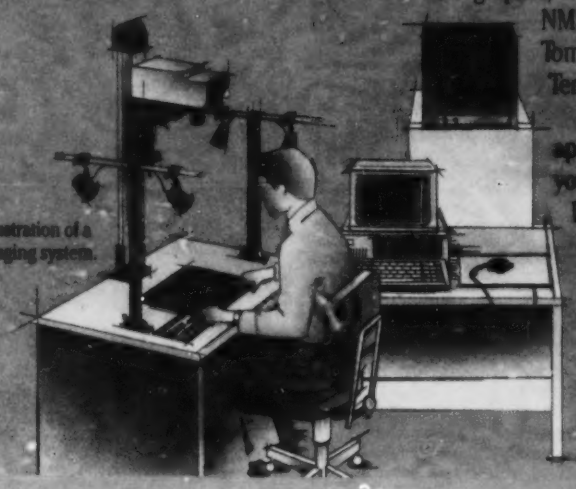

Illustration of a typical imaging system.

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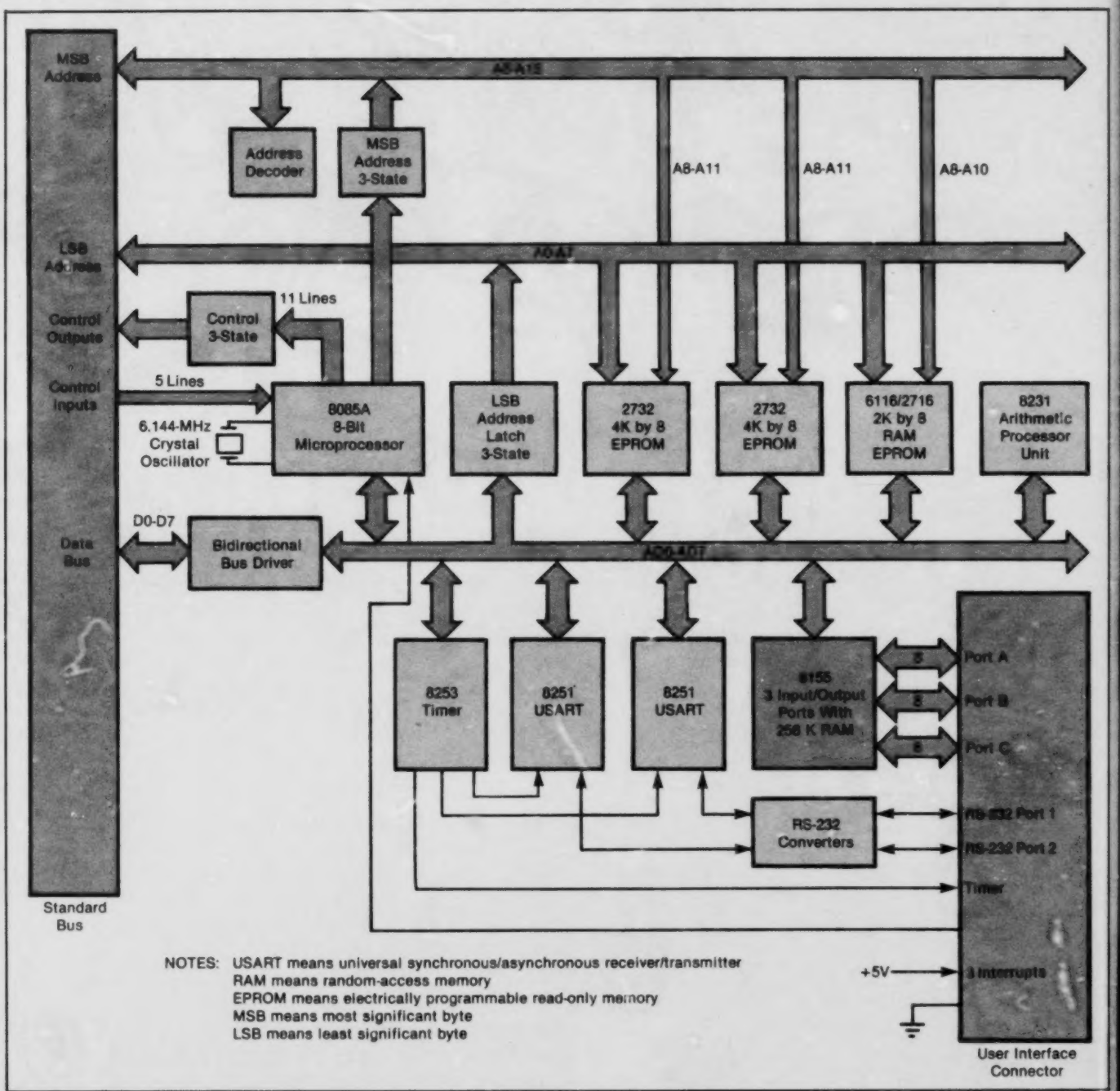
Airborne Instrumentation Computer System

A modular microcomputer provides real-time data processing and telemetry-interface functions.

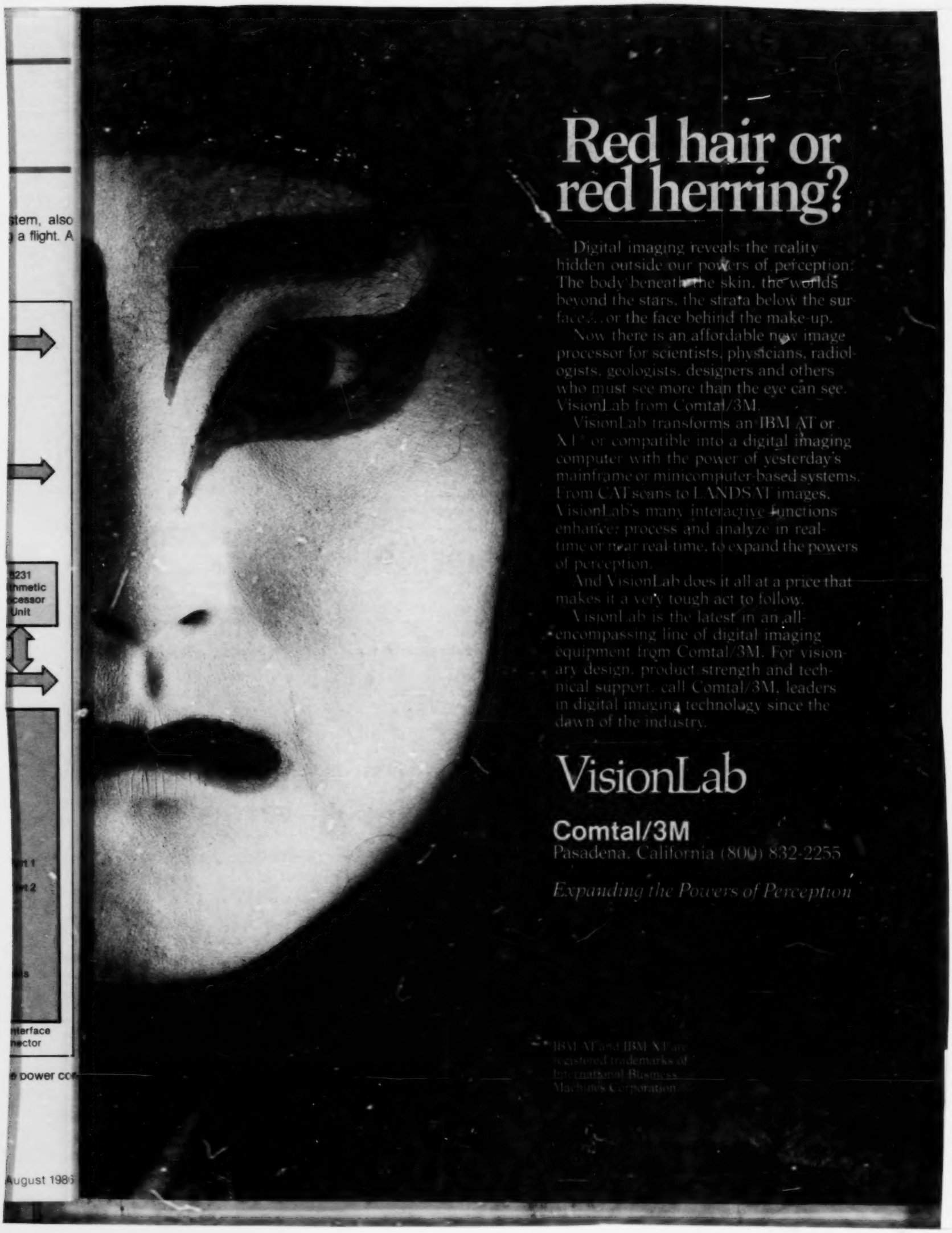
Ames Research Center, Moffett Field, California

A programmable instrumentation system links pulse-code-modulation (PCM) telemetry to digital systems on test aircraft. The system, called AICS for airborne instrumentation computer system, also analyzes flight-test data during a flight. A



NOTES: USART means universal synchronous/asynchronous receiver/transmitter
RAM means random-access memory
EPROM means electrically programmable read-only memory
MSB means most significant byte
LSB means least significant byte

The **Single-Board Microcomputer** in the AICS includes only commercially available VLSI circuits. In typical applications, the power consumption is less than 50 W.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A block diagram of the single-board AICS computer is shown in the figure. The interface to the PCM telemetry system uses two additional printed-circuit cards (not shown). By virtue of its programmability and its use of the STD bus with plug-in cards, the AICS can be quickly adapted to different projects.

The 114-by-165-mm, six-layer computer board plugs into the STD-bus backplane mounted in a 254-by-133-by-140-mm enclosure. The backplane can accommodate six printed-circuit cards.

The computer includes an 8085A 8-bit microprocessor and an 8231 arithmetic processor with a 32-bit internal data path for performing single- and double-precision floating-point arithmetic and scientific calculations.

AICS software is prepared in assembly language on a minicomputer with a relocating cross assembler having macro and subroutine capability. A real-time hardware emulator is used for program testing.

The AICS has been used on an F-15 aircraft as an interface between two digital electronic engine-control computers and a PCM telemetry system. Because of the flexibility of the AICS design, only software modifications and one additional line-receiver card are required to adapt the AICS from the F-15 application to one on an F-111 aircraft with a complex, two-computer control system used to study a variable-camber wing. The AICS has also been used on an OV-1C Mohawk aircraft to test a stall-warning concept, a more complex application that illustrates the potential power of the system.

The interface to the PCM telemetry system can provide up to 16-bit data words. Since the PCM interface must provide a data word on demand within 4 microseconds, asynchronously with other AICS processes, the PCM interface contains a separate 16-bit-word buffer memory with a direct-memory-access controller. To send 16-bit words via a 10-bit-word telemetry system, the interface sends a 10-bit word followed by a 6-bit word for each DMA access.

This work was done by Glenn A. Bever of **Ames Research Center**. *Further information may be found in NASA TM-86036 [N84-20521/NSP], "The Development of an Airborne Instrumentation Computer System for Flight Test."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161. Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11602.

VLSI Architectures for Computing DFT's

Simplifications result from the use of residue Fermat number systems.

NASA's Jet Propulsion Laboratory, Pasadena, California

A system of finite arithmetic over residue Fermat number systems enables the calculation of the discrete Fourier transform (DFT) of a series of complex numbers with a reduced number of multiplications. The computer architectures based on this approach are suitable for the design of very-large-scale integrated (VLSI) circuits for computing DFT's. The general approach may not be limited to DFT's; it may also be applicable to the decoding of error-correcting codes and to other transform calculations.

A complex integer can be represented by a pair of residues modulo a Fermat number, F_n, where $F_n = 2^{2^n} + 1$. The ring of residues of integers modulo F_n is designated as Z_{F_n}. The set $Z_{F_n}[i] = \{a + ib | a,b \in Z_{F_n}\}$ contains F_n^2 elements. Over this set, addition is given by

$$(a + ib) + (c + id) = (a + c)_{F_n} + i(b + d)_{F_n}$$

while multiplication is given by

$$(a + ib)(c + id) = (ac - bd)_{F_n} + i(bc + ad)_{F_n}$$

where the subscript F_n denotes the residue of a modulo F_n. An important mapping in this system is specified by $\phi: a + ib \rightarrow [(a + sb)_{F_n}, (a - sb)_{F_n}] = (\alpha, \bar{\alpha})$ where $\alpha = (a + sb)_{F_n}$, $\bar{\alpha} = (a - sb)_{F_n}$, and $s = \pm 2^{2^{n-1}}$.

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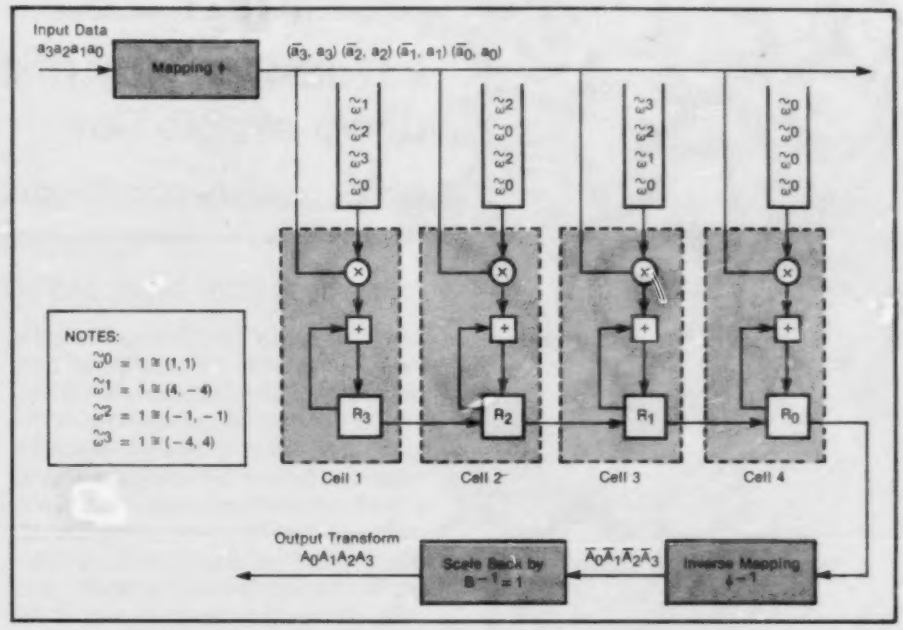
A recently developed algorithm makes it possible to compute the DFT using the direct sum S_{F_n} of two copies of residue number systems Z_{F_n}. A principal advantage of this algorithm is that a complex multiplication can be done by using similar integer multiplications in two parallel, independent residue channels. Building on this idea, it has been found that a complex-integer DFT can be computed by multiplication modulo a Fermat number in two parallel, independent residue channels.

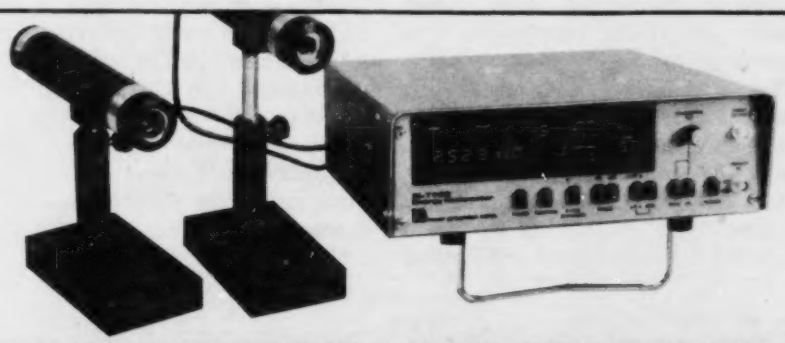
Such a multiplication over the direct sum of two copies of Z_{F_n} can be used in the implementation of a systolic array of the DFT. A VLSI architecture has been developed for computing the d-point DFT over the direct sum S_M of $Z_{F_{k+j}}$, using two copies of the finite ring $Z_{F_{k+j}}$ for all j. The VLSI processor is composed of d basic cells.

The figure shows an example of this architecture for a four-point DFT in $Z_{17}[i]$. First, the integer complex-number sequence a_n is converted from $Z_{17}[i]$ into $(a_i, \bar{a}_i) \in S_{17}$ for $1 \leq i \leq 4$ and sent to all the cells simultaneously. Each register is composed of two five-bit subregisters containing $(\alpha, \bar{\alpha})$. Initially, all registers are set at zero. After the input data are entered, the components A_k (in S_{17}) of the DFT are contained in registers B_1 through B_3. The values computed in this manner are shifted sequentially out of register R_0. These values are then converted by the inverse mapping ϕ^{-1} into $\tilde{A}_k = a_k + ib_k$ for $0 \leq k \leq 3$. Finally, these $\tilde{A}_k$ are returned to the scale of the original complex numbers by $B^{-1} = 1$ for $1 \leq k \leq 4$.



This Systolic Array would be used to compute a 4-point DFT over the direct sum, S_{17}, of two copies of Z_{17}. This system is readily implemented in VLSI.

This work was done by Trieu-Kie Truong, Jaw John Chang, In-Shek Hsu, Irving S. Reed, and Ding-Yai Pei of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 98 on the TSP Request Card.*
NPO-16656



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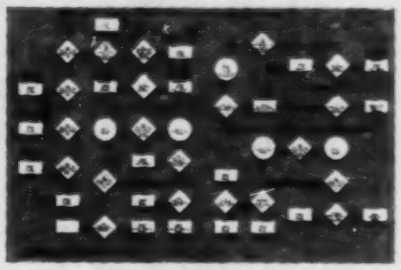

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Books & Reports

63 Convection in a Solidifying Binary Mixture

Interferometer for Observing Compressible Flow

Moving pictures show changing flow-field contours.

Ames Research Center, Moffett Field, California

A new optical interferometer enables the instantaneous visualization of compressible fluid flows. Because it is relatively immune to vibration, the unit is well suited to the observation of flows over models in large wind tunnels. By noting the relationships between fringe shifts, refractive indices, and densities, an experimenter can map the flow-field density contours. Since the relationships among the density, pressure, and velocity are fairly well understood theoretically, the interferometer can give a quantitative, time-resolved characterization of the flow field.

The new interferometer (see figure) combines elements of the schlieren and point-diffraction interferometers. The light source would ordinarily be a laser, but, with sufficiently precise optics, an incoherent source can sometimes be used. The light beam is first spatially filtered, expanded by lens 1, then collimated by spherical mirror 3 into a broad beam that crosses the experimental volume. The beam is then focused by mirror 4 and recollimated into a narrower beam by lens 2.

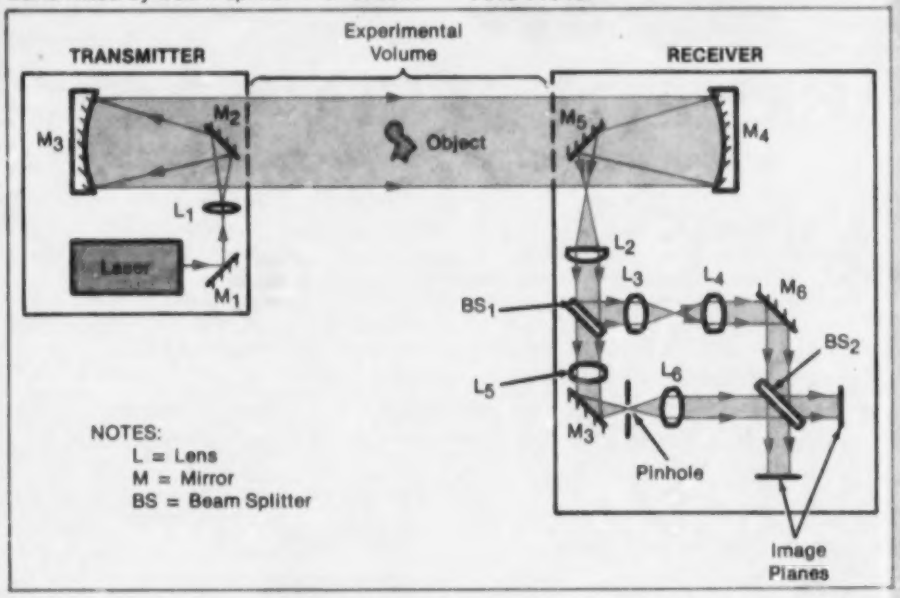
The portion of the beam reflected by beam splitter 1 is focused by lens 3, recollimated by lens 4, and passed on to beam splitter 2. This portion contains the diffraction imposed on the object beam by the experiment. The part of the beam transmitted by beam splitter 1 is focused by lens 5, then passed through a pinhole to remove the experimental diffraction pattern and generate a spherical reference beam.

The reference beam is collimated by lens 6 and recombined with the reflected part of the object beam at beam splitter 2. Both the transmitted and reflected outputs of beam splitter 2 can be used. The recombined beams interfere on the image planes, producing interference fringes that can be observed directly and photographed while the experiment continues.

The interferometer has been demonstrated by producing images of the flow around a candle, a propane torch, a heated cylinder, and an oscillating airfoil in a wind tunnel. Future developments will include the refinement of the optics, the selection of advanced recording media, and quantitative comparisons to holographic interferometry (which does not have real-time capability, unlike the new technique).

This work was done by W. D. Bacnalo and M. J. Houser of Aerometrics, Inc. for **Ames Research Center**. *For further information, Circle 43 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11549.



In the Improved Point-Diffraction Interferometer, the reference beam is generated by pinhole (point) diffraction at a place in the object beam outside the experimental volume. The object under test is positioned so that its interior or its supporting stand (for which no interferogram is normally required) lies in the shadows of turning mirrors 2 and 5.

Ultrasonic Verification of Metal-Grain Size

The heat treatment of a sample of known material can be measured.

Lewis Research Center, Cleveland, Ohio

Ultrasonic attenuation as a function of frequency can be determined for a metal sample having a known mean grain diameter. It has been demonstrated at the Lewis Research Center that once this function is determined for one sample of a material, it can be scaled to determine the mean grain size of other samples of the material. The results suggest that an ultrasonic approach is viable for verifying the effects of the heat treatments that vary the grain size. Thus, an in situ, nondestructive method is available for verifying the degree and correctness of heat treatment in metals-processing facilities.

Advanced techniques are used for the ultrasonic interrogation of heat-treated metals. It has been shown that the ratio between the wavelength and mean grain diameter is a significant factor in comparing changes in microstructure. This ratio can be used to determine a scale factor between two polycrystalline materials having different mean grain diameters. These results are achieved by determining the attenuation as a function of frequency without reference to any particular scattering mechanism. By this approach, it is unnecessary to associate a particular wavelength with the mean grain diameter. This allows a generalized formulation for scaling the mean-grain-diameter variations among samples of polycrystalline material that has undergone heat treatment.

Representative sets of experimentally-based calibration curves are shown in the figure. The heat treatment of an unknown sample can be verified by comparing its attenuation curve to the calibration set for the material. Possible uses of this technology include nondestructive ultrasonic verification of heat treatments and other online inspection systems.

This work was done by Edward R. Generazio of **Lewis Research Center**. *Further information may be found in NASA TM-83788 [N84-32849/NSP], "The Role of the Reflection Coefficient in Precision Measurement of Ultrasonic Attenuation."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
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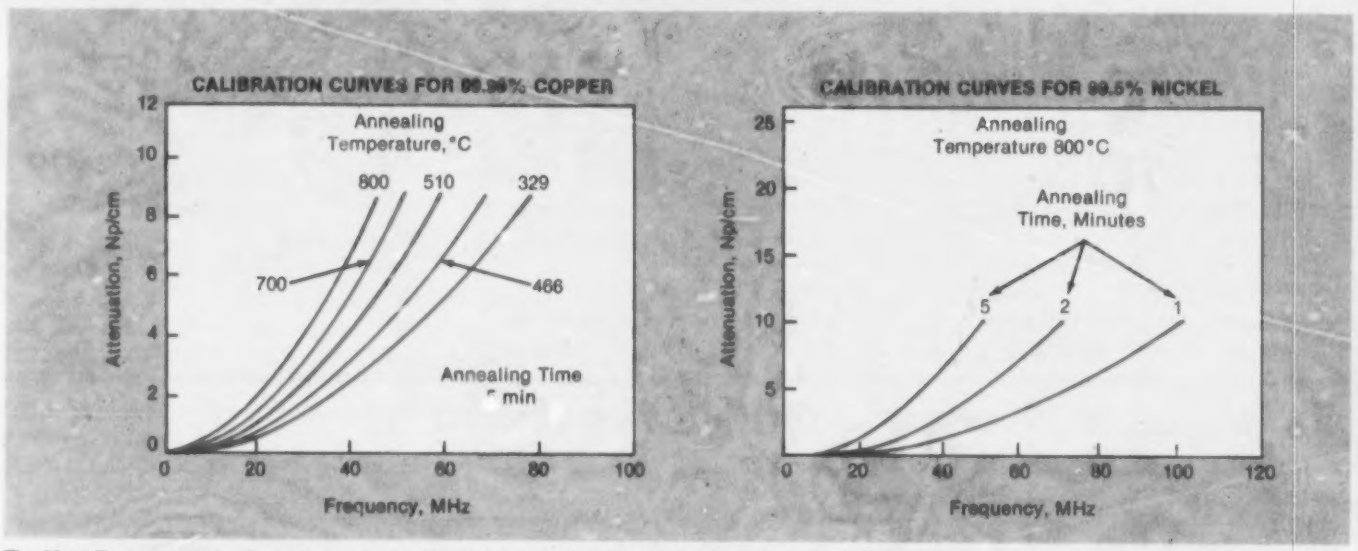


The **Heat Treatment of a Sample** can be verified by comparing its attenuation curve to the set of calibration curves for the sample material.

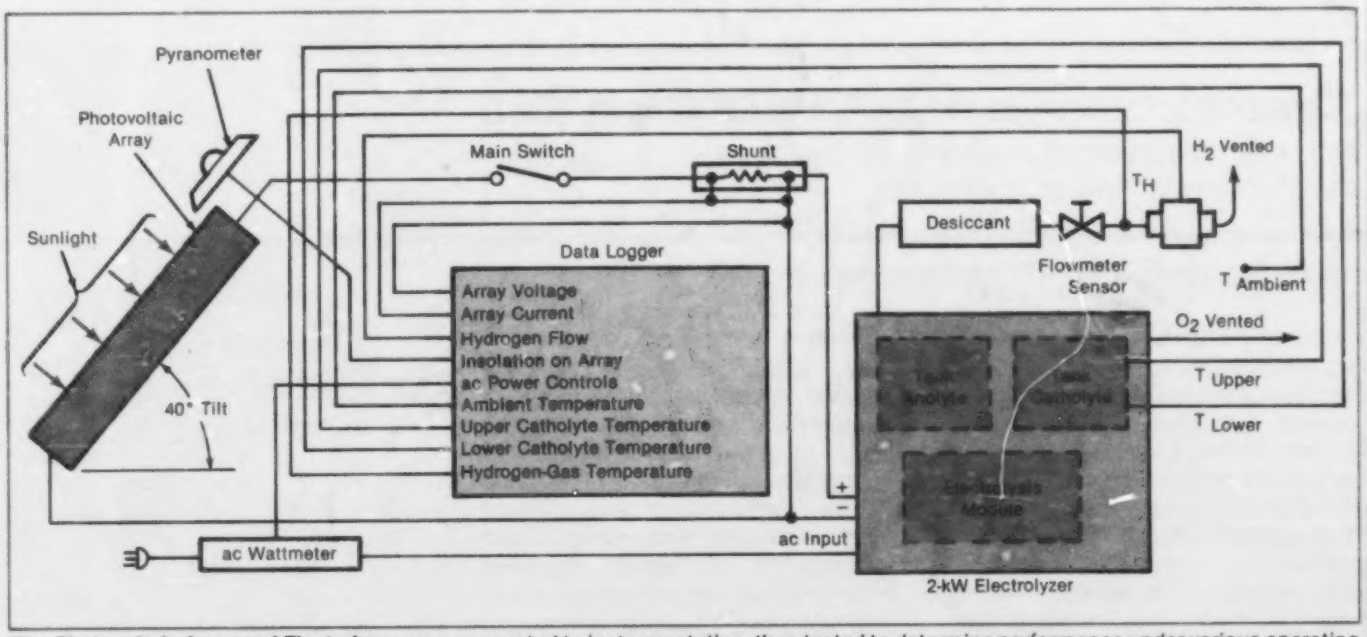
Solar-Powered Water Electrolyzer

Field trial provides data for an economic assessment.

John F. Kennedy Space Center, Florida

An experimental solar-powered water electrolyzer operates efficiently and with the promise of favorable economics. The electrolyzer produces hydrogen and oxygen from water using solar photovoltaic electricity directly, without conditioning. The hydrogen could be used as an energy-storage medium to be burned when needed to generate heat or electricity for domestic use.

The system consists of a commercial photovoltaic array with a 1-kW peak-power rating and a scaled-down version of a commercial electrolyzer. The electrolysis module consists of 15 cells, each having an effective diameter of 5.19 cm and an allowable current density of 600 mA/cm^2. The electrode area and the number of cells, which determine the current and the voltage demand, respectively, were selected to match the peak



The **Photovoltaic Array and Electrolyzer** were connected to instrumentation, then tested to determine performance under various operating conditions.

power output of the solar array. An asbestos diaphragm separates the anode and the oxygen from the cathode and the hydrogen in each cell. Controls and alarms use commercial ac power distinct from the dc supplied by the photovoltaic cells.

The unit functions with an energy efficiency (the ratio of energy in the hydrogen to that delivered by the solar cells) of about 50 to 75 percent, the exact value depending on the weather and the operating schedule. The overall system efficiency is about 4 percent — a respectable figure in view of the inherent inefficiency of photovoltaic conversion.

The system (see figure) was tested for 3 months in Florida. From the data collected during this trial, an economic analysis was made by extrapolating to a 4-kW residential system. Such a system is expected to produce 500 kWh per month in Florida, on the average. Since the average Florida residence uses about 1,000 kWh per month, or double the output of a 4-kW electrolyzer, this size is appropriate for a basic module.

According to the analysis, the cost of 1 kWh of energy as hydrogen gas would be 73 cents in 1983-84 and only 17 cents in 1995. These costs include allowances for the photovoltaic array, the electrolyzer, maintenance, electrolyte replacement, electrolysis-module replacement, property tax, insurance, and Federal income tax credit. The electrolyzer cost for 1983-84 was based on a production rate of 200 units per year and for 1995 on a rate of 20,000 units per year.

The economics can be improved if a use can be found for the oxygen generated with the hydrogen and its value included in the analysis. In addition, if the hydrogen were used with a fuel cell during cloudy periods and at night, the combined heat from the electrolyzer and fuel cell could provide all the hot water needed for the household.

This work was done by Omar J. Hancock, Jr., of the Florida Solar Energy Center for **Kennedy Space Center**. *For further information, Circle 87 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11297.

Ellipsometric Monitoring of Film Deposition

Impurities would be detected nondestructively during processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

Ellipsometry has been proposed as a nondestructive method of detecting impurities in films of amorphous silicon during plasma deposition. Because ellipsometry can monitor only the surface layer it "sees," it can monitor the deposition conditions continuously throughout the process, alerting the operator to the need to make adjustments and making it unnecessary to destroy samples in post-deposition analysis. Such monitoring would not disturb the deposition process appreciably.

An ellipsometer — also called more descriptively a spectral polarimeter — measures the polarization of light of a specific wavelength reflected from the surface under observation. The reflected light is generally elliptically polarized. The measured polarization components are used to calculate the real and imaginary parts of the index of refraction, which represent dielectric permeability and absorption, respectively, of the surface material at the given wavelength.

In the proposed system, the surface of a growing amorphous-silicon film would be monitored by an ellipsometer at a wavelength or combination of wavelengths at which the impurity or impurities of interest absorb light strongly. For example, oxygen absorbs strongly in the infrared at a wavelength of about 9 μm, while silicon is nearly transparent at this wavelength. This strong contrast between silicon and oxygen should permit ellipsometric determinations of oxygen content in the amorphous-silicon surface layer.

A conventional ellipsometer has to be modified in several ways before it is incorporated in the proposed system. The visible light source (usually a laser) must be replaced with a suitable infrared or other source for the wavelengths of interest. The instrument must be built into the plasma-deposition chamber, with the light source on one side, the detector on the other. All windows and optical surfaces must be far enough from the plasma to avoid film deposition.

Experiments have shown that the depo-si-

tion plasma does not affect the polarization. However, optical absorption by the plasma reduces the strength of the reflected light, and radiation from the plasma enters the detector. To decouple the plasma radiation from the reflected light, the light source could be chopped and the detector synchronized with the source.

This work was done by Donald B. Bickler of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 2 on the TSP Request Card.* *NPO-16791*

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Convection in a Solidifying Binary Mixture

Temperature and concentration profiles are calculated.

A paper discusses the theory of interrelated problems of heat transfer and material distribution in a solidifying binary alloy. The study expands on earlier work by including more realistic, mathematically complicating physical effects and yet retains a simple geometry and enough simplifying assumptions to make the equations solvable. The study will lead to improved understanding of metal and glass production, material processing in low gravity, and other important material processing problems.

The model of the system is a binary alloy slab of infinite width and finite depth. Heat is removed from the upper and lower slab surfaces by convection, with solidification starting at the lower surface. The solidification front moves up, releasing latent heat of solidification at the interface. The solid and liquid have different densities, causing a volume change and motion of the upper surface during freezing.

There is no mass flow across the upper and lower surfaces. The model does, however, include mass diffusion within the liquid and solid. Because the substance is an alloy, the freezing temperature depends on the composition at the interface, and the model takes this effect into account.

Four governing equations are derived from the standard expressions for time-dependent thermal and mass transport. The first equation expresses the relationship among the liquid temperature and its spatial derivatives, the liquid and solid densities, the interface position, and the thermal diffusivity of the liquid. The second equation relates the solute concentration and and its spatial derivatives in the liquid to the densities, the interface position and the solute diffusivity in the liquid. The third and fourth equations are conventional expressions for the temperature and solute diffusion in the solid.

The interface conditions include two equations, based on the conservation of mass and energy at the interface. The solid and liquid at the interface are assumed to be at the concentration-dependent equilibrium melting temperature. The thermal boundary conditions at the upper and lower surfaces are expressed by equating the conductive heat fluxes within the adjacent alloy to the convective heat fluxes outside.

Although the governing equations are linear, the interface conditions are not. As a consequence, the coupled equations are nonlinear. One numerical solution method involving a Runge-Kutta integrator fails at low diffusion rates of solids. A second method involves closed-form, analytical solutions and reaches lower diffusion rates (though not as low as desired).

This work was done by B. Antar and F. Collins of the University of Tennessee for **Marshall Space Flight Center.** *For further information, Circle 5 on the TSP Request Card.* *MFS-27092*

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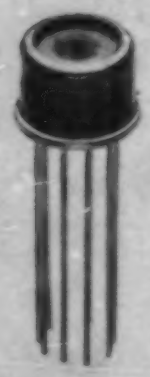

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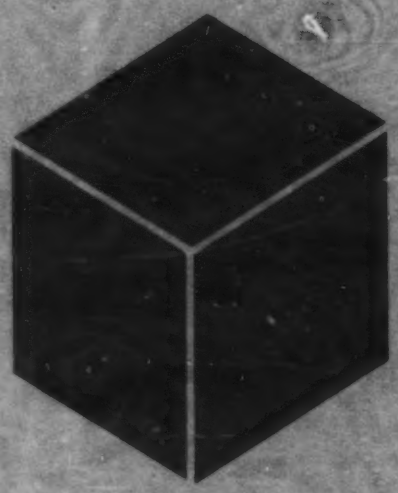
Materials



Hardware, Techniques, and Processes

64 Fire-Resistant Polyimides Containing Phosphorus
66 Sulfone/Ester Polymers Containing Pendent Ethynyl Groups
68 Powder Extinguishants for Jet-Fuel Fires
69 Process for Making Tris(N-methylamino) Methylsilane
69 Composite Lightning Rods for Aircraft

Fire-Resistant Polyimides Containing Phosphorus

The limiting oxygen index is increased.

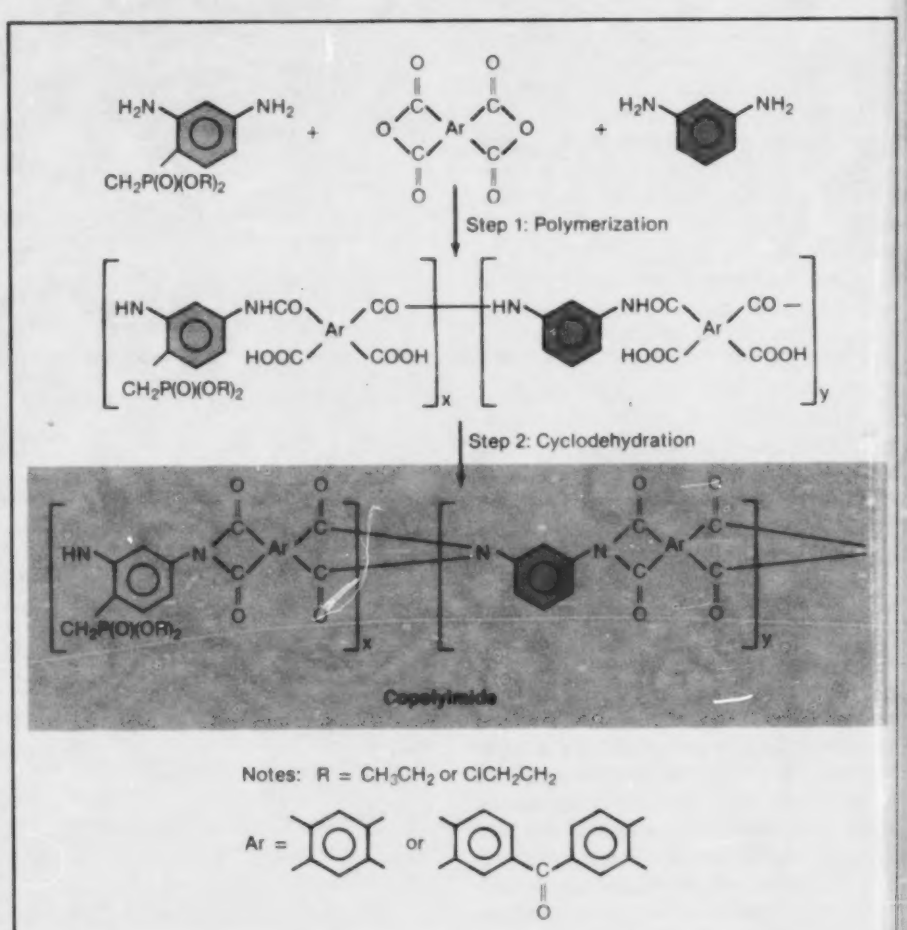
Ames Research Center, Moffett Field, California

Polyimides having increased fire resistance have been made by reacting 1-[(dialkoxyphosphinyl)methyl]-2,4- and -2,6-diminobenzenes (compound 1 isomers) with such tetracarboxylic dianhydrides as pyromellitic dianhydride (PMDA) and benzophenone tetracarboxylic dianhydride (BPTDA). Copolyimides have also been synthesized from the reactions of compound 1 and m-phenylenediamine with the dianhydrides.

Compound 1 is made from the corresponding (dialkoxyphosphinyl)methyl benzenes by nitration followed by catalytic hydrogenation. The 2,4 and 2,6 isomers are formed in relative amounts of about 9 and 1, respectively. Separation of the isomers is not necessary; the compound 1 isomer mixture can be used as is to make polyimides and copolyimides.

The reaction of the predominant 2,4 isomer with a comonomer and a tetracarboxylic dianhydride is shown in the figure. The copolymer is formed in a two-step polycondensation process. The first step is carried out at 20 to 50 °C in a solvent of dimethyl sulfoxide, N,N-dimethyl formamide, or N,N-dimethyl acetamide. This step produces a polyamic acid in a fast, exothermic reaction.

The second step is cyclodehydration, which can be done thermally or chemically. In the thermal method, the solvent is first removed at 75 °C, and the polymer is then heated at 300 °C in a vacuum for 2 hours. In the chemical method, the water of cyclization is azeotropically removed with benzene or removed by stirring at room



A Copolyimide With a Group Containing Phosphorus is synthesized from a 1-[(dialkoxyphosphinyl)methyl]-2,4-diaminobenzene (top, left), m-phenylenediamine (top, right), and a tetracarboxylic dianhydride (top, middle). The copolymer is more fire resistant than the corresponding polyimide without phosphorus.

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temperature in acetic anhydride with pyridine as a catalyst. The polymer thus precipitated is heated to 200 °C in a vacuum for 2 hours to complete the cyclization reaction.

Phosphorus-bearing polyimides and copolyimides prepared in this way were compared with the corresponding polyimides without phosphorus, prepared from m-phenylenediamine and PMDA or BPTDA. The glass-transition temperatures were reduced by the incorporation of the (dialkoxyphosphinyl)methyl groups. The molecular weights and thermal stabilities of the copolymers were found to decrease with the increasing concentration of the moieties containing phosphorus. However, the copolyimides containing phosphorus showed considerably more resistance to fire as measured by the limiting-oxygen-index test.

This work was done by John Mikroyannidis of **Ames Research Center**. *For further information, Circle 28 on the TSP Request Card.*

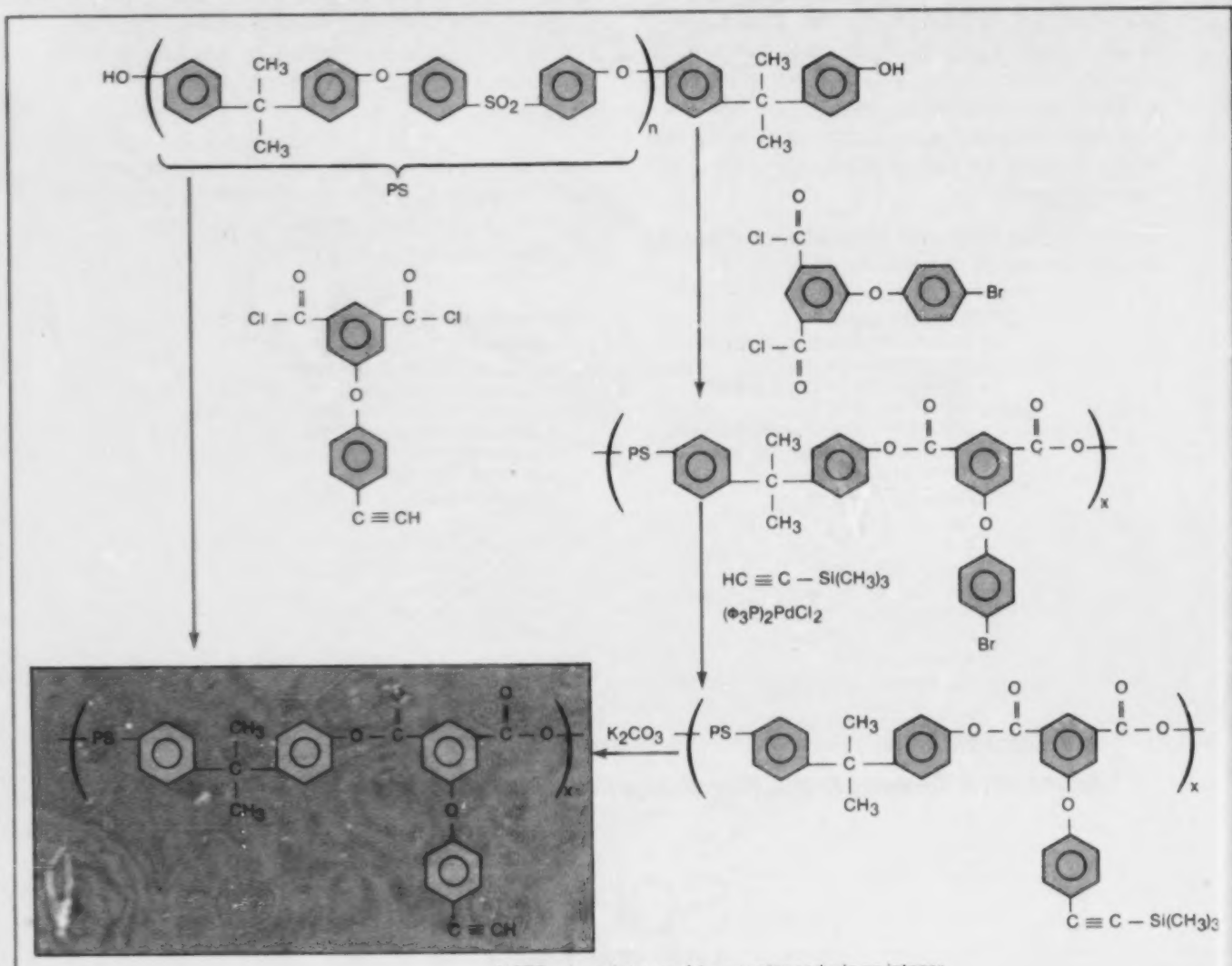
This invention has been patented by NASA (U.S. Patent No. 4,536,565). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11522.

Sulfone/Ester Polymers Containing Pendent Ethynyl Groups

Two processes make these high-performance polymers resistant to solvents, without compromising the mechanical characteristics.

Langley Research Center, Hampton, Virginia

A variety of polysulfones and polyesters is commercially available for use in such applications as adhesives, moldings, membranes, and composite matrices. The un-cross-linked forms of these materials are tough and thermoformable but sensitive to certain solvents, especially under load. As a result, these materials are unacceptable for use as resin matrices in composite structures on commercial and military aircraft, where resistance to fluids and paint strippers is an essential



NOTE: n is an integer of 1 or greater and x is an integer.

Sulfone/Ester Polymers containing pendent ethynyl groups are prepared by a direct process (large arrow) or by a multistep process (small arrows).

requirement.

Two processes have been developed for preparing an improved class of high-performance polymers. These polymers show improved solvent resistance while retaining high toughness, thermoformability, and mechanical performance. Sulfone/ ester polymers containing pendent ethynyl groups are prepared by a direct or a multistep process. The multistep process involves the conversion of a pendent bromo group to the ethynyl group, while the direct process involves reacting hydroxy-terminated sulfone oligomers or polymers with a stoichiometric amount of 5-(4-ethynylphenoxy) isophthaloyl chloride. The two different processes are shown in the figure.

The preferred direct route is depicted in the left portion of the reaction equation and involves the reaction of hydroxy-terminated sulfone oligomers, also referred to as arylene ether sulfone oligomers, with 5-(4-ethynylphenoxy) isophthaloyl chloride. The multistep route is shown in the right portion of the equation and involves the reaction of hydroxyterminated sulfone oligomers with 5-(4-bromophenoxy) isophthaloyl chloride to form a sulfone/ester polymer containing pendent bromo groups. The bromo groups are displaced by trimethylsilylacetylene using a palladium catalyst followed by cleavage of the trimethylsilyl group to the ethynyl group with a weak base.

The ethynyl-group content and, accordingly, the cross-link density of the cured polymer may be readily controlled in both processes. High ethynyl-group content provides high cross-link density in the cured resin. The material properties of toughness, stiffness, solvent resistance, and processability are also controlled by ethynyl-group content. Polymers containing high ethynyl-group content are generally more difficult to process (less flow due to reactions of the ethynyl groups) than those with lower ethynyl-group content and, when cured, are not as tough as those with lower ethynyl-group content (lower cross-link density). Conversely, cured polymers with higher ethynyl-group content (higher cross-link density) are stiffer (higher modulus) and have better solvent resistance and higher use temperatures.

The synthesis of sulfone/ester polymers containing pendent ethynyl groups can be readily controlled to adjust the chemical composition for use in specific applications. As prepared, the sulfone/ester polymers containing pendent ethynyl groups are readily soluble in a variety of solvents. Solutions can be used to cast films, form coatings, or impregnate reinforcement materials to form adhesive tapes and prepregs. The solvent can be removed, and when the resultant polymer is heated in the range of 200 to 300°C, the ethynyl groups react to provide branching and cross-linking. The cured resin is insoluble, although swelling in certain solvents, depending on the cross-link density, is observed.

The synthesis may also be used to place pendent ethynyl groups onto a variety of polymers in addition to sulfone/ esters. Potential applications for the new sulfone/ester polymers containing ethynyl groups include adhesives, composite resin matrices, moldings, ultrafiltration membranes, protective coatings, and such electrical insulators as thin films for microelectronic circuitry.

This work was done by Paul M. Hergenrother and Brian J. Jensen of **Langley Research Center.** *For further information, Circle 27 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center (see page 29). Refer to LAR-13316.

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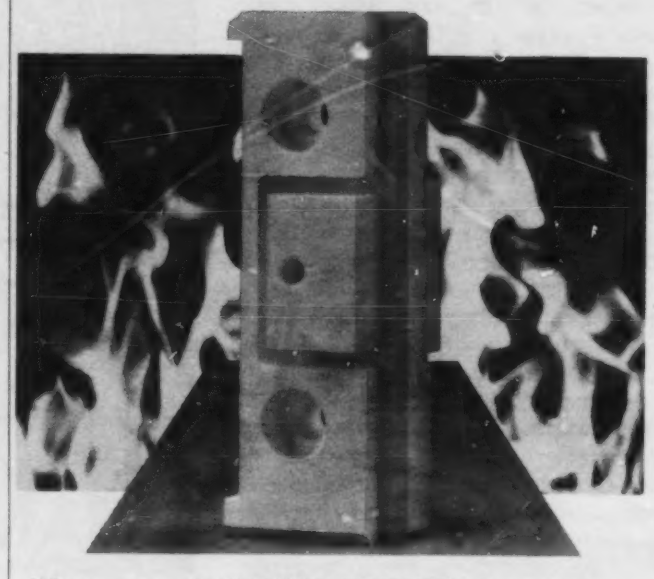

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Powder Extinguishants for Jet-Fuel Fires

Mixtures of alkali metal dawsonite and metal halide show superior performance.

Ames Research Center,
Moffett Field, California

In tests of new dry powder fire extinguishants, mixtures of potassium dawsonite [$KAl(OH)_2CO_3$] with either stannous iodide (SnI_2) or potassium iodide (KI) were found most effective for extinguishing jet-fuel fires on hot metal surfaces (up to 900 °C). These mixtures performed more effectively than either compound alone. This is particularly striking since KI was one of the most effective extinguishants known previously.

Alkali metal dawsonites can be prepared as follows: Equimolar quantities of aluminum hydroxide and an alkali metal hydrogen carbonate powder of particle size less than 90 μm are thoroughly mixed and transferred to an open-topped vessel made of aluminum or other metal that is chemically inert to the ingredients. The vessel is placed in a high-pressure reactor, which is then flushed and pressurized to 120 to 360 psig (830 to 2,500 kPa) with CO_2 gas. The reactor is then quickly heated to 150 to 200 °C and held at that temperature for 1 to 6 hours. After cooling and depressurization, the product is dried in a vacuum oven at 50 °C.

Mechanical mixing of the dawsonite and iodide components is adequate for preparing the extinguishant mixtures. The ingredients should be finely divided, about 250 to 350 mesh (about 62 μm maximum particle size). To ensure that the resultant mixture will pour well, moisture should be driven off from the iodide (either before or after mixing) and the mixture kept in an airtight container. The mixture must be readily pourable so that it will spread rapidly and evenly over the burning surface.

The performance of single compounds and two-component mixtures was evaluated in two tests. In the static test, jet fuel (type JP-4) dripped continuously into an electrically-heated stainless-steel trough. After a flame developed and reached a fairly steady state, the extinguishant powder was applied to the flame while the input of heat and fuel continued. The time the flame took to rekindle was taken as a measure of extinguishant effectiveness.

In the flow test, a fuel leak (such as might occur in aircraft) was simulated by spraying the fuel into a heated duct with air flowing through it. Rekindling time was again taken as the measure of effectiveness.

Static- and flow-test results are shown in the table both for individual compounds and for mixtures containing one aluminum compound and one metal halide. At 900 °C the

FLOW TESTS

DRY CHEMICALS	Grams	Reignition Delay Time, s, at Various Airflows, m/s	
		6 (m/s)	36 (m/s)
(1) KD*	30	>20	0.5
(2) KD + KCl (32%)	10-20	2	>20
(3) KCl (PYROCHEM)	30	<1	0
(SUPER-K)	50	—	20
(4) KD + KI (10%)	20	3	>20
(5) KI	40	<1	0
(6) KD + KI (5%)	20	1	<1
	25	>20	—
(7) KD + KI (9%)	15	<1	<20
(8) KD + KI (18%)	20	<1	>20
(9) KD + SnI_2 (5%)	15	>20	>20
(10) KD + SnI_2 (10%)	15	>20	>20
(11) KD + SnI_2 (20%)	10	>20	>20

Notes: Mixtures 6 to 11 were preheated.
*KD = potassium dawsonite, $KAl(OH)_2CO_3$.

STATIC TESTS

INGREDIENTS	Reignition Delay Time at Noted Temperature, s			
	700 °C	750 °C	800 °C	900 °C
(1) KD		153 ± 15		10 ± 4
(2) KD + SnI_2 (6% I)		520 ± 52		51 ± 3
(3) KD + SnI_2 (6% I)		419 ± 61		50 ± 2
(4) SnI_2 (68% I)	380 ± 80			2 ± 2
(5) KD + KI (7% I)		500 ± 90		13 ± 4
(6) KD + KI (7% I)		>900		50 ± 14
(7) KI (76% I)	>900		16 ± 6	2 ± 2
(8) $Al(OH)_3$		100 ± 30		3 ± 2
(9) $Al(OH)_3$ + SnI_2 (7% I)		204 ± 20		8 ± 1
(10) $Al(OH)_3$ + KI (7% I)		72 ± 3		8 ± 1
(11) $Al(OH)_3$ + KI (8% I)		233 ± 56		—
(12) AlOOH		48 ± 35		None
(13) AlOOH + KI (7% I)		131 ± 7		15 ± 4
(14) Al_2O_3		28 ± 12		None
(15) Al_2O_3 + KI (7% I)		>900		50 ± 12
(16) NaI (85% I)	600 ± 60			3 ± 2
(17) $NaAl(OH)_2CO_3$		296 ± 50	29 ± 5	6 ± 3

Notes: Mixtures 2, 5, 9, and 11 were mechanical mixtures; mixtures 3, 6, 10, 13, and 15 were preheated.

Fire Extinguishant Test Results show longer reignition delays at the higher test temperatures when mixtures of an alkali dawsonite and a metal halide are used than when either component is used alone. The percentage of iodine by weight in each mixture is shown in parentheses.

mixtures consistently outperformed their individual components. At lower temperatures, both KI alone and mixtures containing KI performed very well.

While these results are very promising, further development work might be required to develop practical systems using the new mixtures. For example, the hygroscopic tendencies of the iodides would have to be considered in designing storage for the mixtures.

This work was done by Robert L. Altman of **Ames Research Center** *and Ludwig A. Mayer and Alan C. Ling of San Jose University. No further documentation is available.*

This invention has been patented by NASA (U.S. Patent No. 4,406,797). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11252.

Process for Making Tris(N-methylamino) Methylsilane

This efficient process will aid the production of silicon carbide/silicon nitride fibers.

Marshall Space Flight Center, Alabama

A process for making tris(N-methylamino) methylsilane (TNMAMS) allows this important precursor of silicon carbide/silicon nitride ($Si_xN_yC_z$) fibers to be produced on a large, economically acceptable scale. $Si_xN_yC_z$ fibers are produced by the thermal polymerization of TNMAMS to polycarbosilizane resin, which is then drawn and pyrolyzed. These fibers are 10^6 times as electrically resistive as carbon fibers while having similar mechanical properties; consequently, they are promising replacements for carbon fibers in composite materials in which high conductivity would pose a hazard.

The new preparation of TNMAMS involves the gradual addition, under dry nitrogen, of x moles of dry methyltrichlorosilane to a solution of 10x moles of methylamine in a dry, inert solvent (e.g., petroleum ether). (Water must be excluded because it engages in competing chemical reactions.) During the addition, the temperature is maintained at about −30 °C. The methyltrichlorosilane must be added slowly to insure that the byproduct hydrochloric acid reacts mainly with the excess methylamine (rather than with the product TNMAMS) to produce an insoluble salt.

When the addition is complete, the reaction mixture is warmed to about 40 °C and kept at that temperature for about 60 minutes. The byproduct salts are then removed by filtration. Finally, the solvent is removed by distillation, leaving the TNMAMS, which is a clear liquid at room temperature.

The synthesis was demonstrated in a large-scale reaction starting with 1,150 g (900 ml) of methyltrichlorosilane. After distillation, 673 ml of TNMAMS remained, the yield being 58.6 percent by weight.

This work was done by Johnny M. Clemons, Benjamin G. Penn, and Frank E. Ledbetter III of **Marshall Space Flight Center.** *For further information, Circle 54 on the TSP Request Card.*
MFS-28143

Composite Lightning Rods for Aircraft

Sacrificial tips protect composite parts of modern aircraft.

Langley Research Center, Hampton, Virginia

The problem of protecting aircraft from electrostatic discharges and lightning strikes has stimulated a variety of protective measures including both passive and active dischargers. The problem becomes more severe as insulating composites replace more and more of the Faraday shield inherent in all-metal construction. Also, modern electronics and the practice of entrusting vital flight functions to computers creates a need for protection from electrical charges that can induce disruptive currents in the electronic circuits. The composite, lightweight sacrificial tip with graphite was designed especially to reduce lightning-strike damage to composite parts of aircraft and to dissipate the harmful electrical energy.

Extensive damage is often caused by lightning strikes on the relatively nonconductive composite structures now frequently used for the wings, tails, fuselage, or control surfaces on aircraft. This damage often takes the form of delamination and/or holes (complete burnthrough) in the structural surfaces. When the sacrificial tip is installed in a position protruding from the aft surface of an aircraft part made of composite material, the energy from a lightning strike on the part is dissipated through the tip. These tips are very inexpensive and sacrificial but may be usable for withstanding numerous lightning strikes.

The device consists basically of a slender composite rod fabricated from highly-conductive unidirectional reinforcing fibers in a matrix material. These rods are strategically installed in the trailing edges of such aircraft parts as wings, tails, winglets, control surfaces, and the rearward-most portion of the aft fuselage. The rods faricated thus far were of unidirectional graphite fibers in an epoxy matrix, 5/16 in. (0.8 cm) in diameter and 5½ in. (14 cm) long, tapered approximately the last inch (2.5 cm) down to about 50 percent of the major diameter at the tip. This device has already been installed and used successfully on Langley Research Center's F-106 aircraft.

This work was done by Charles F. Bryan, Jr. of **Langley Research Center.** *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to LAR-13470.

Computer Programs

Hardware, Techniques, and Processes

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Electronic Systems

Computer Program for Space-Shuttle Testing

The demand on the Space Shuttle general-purpose computers is reduced.

The Space Shuttle has a number of devices which communicate with the general-purpose computers (GPC's) onboard. Because of the small number of GPC's available, using them to test Space Shuttle hardware and associated software is both inconvenient and expensive. The Simulation Testbed and the Scenario Preprocessor (STB&SPP) system reduces the need for use of GPC's in hardware and software development and testing. The system consists of a computer program, the SPP, and a set of utility subroutines, the STB, which incorporates the Interface Simulator (ISIM).

STB&SPP provides a set of utility test routines that may be linked with user-supplied routines into a user-defined, menu-driven test program for sending GPC messages to a device under test and recording the response of the device. It also provides a facility for sending scenarios of GPC messages to a device under test, simulating in real time the timing and updating of messages as normally performed by the GPC. Finally, SBT&SPP provides a symbolic language, the Scenario Language, for constructing scenarios and translating them into an intermediate language suitable for interpretation by the GPC Interface Simulator.

The STB&SPP system is written in FORTRAN V and Assembler for interactive execution and has been implemented on a Data General Eclipse C330 operating under RDOS with 32K words of extended memory configured as a Shuttle avionics test system (SATS), including a serial-world simulator/serial-word modulator (SWS/SWM). The STB&SPP system was developed in 1983.

This program was written by Martin D. Hyman, Gerald H. Fine, and Gerald J. Hollombe of Abacus Programming Corp. for **Johnson Space Center**. *For further information, Circle 118 on the TSP Request Card.*
MSC-20779

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Circle Reader Action No. 327

Nonlinear Supersonic Full Potential Analysis

Accurate results are obtained for complex geometries.

The Supersonic Implicit Marching Program (SIMP) applies a numerical method, based on the conservative form of the full potential equation, to the problem of three-dimensional supersonic flows with embedded subsonic regions. The conservative formulation of the problem provides the ability to capture shocks and to assess accurately the impact of sweep, thickness, and lift for conditions where linear theory is unsatisfactory.

SIMP fills the need for a nonlinear supersonic technique that produces accurate results for complex geometries, with efficient use of computational resources as well as minimization of the required level of user sophistication. Sample results have been obtained for a variety of problems, including the Space Shuttle orbiter flow at low supersonic mach numbers, flow over realistic fighter configurations, wake simulations for an arrow wing, and a forebody in sideslip.

This analysis method is based on the full potential equations written to conserve mass across shock waves as well as throughout the flow. A conservative switching scheme is used for the transition from a supersonic marching procedure to a subsonic relaxation algorithm. The technique uses characteristic signal-propagation theory to control density biasing for the treatment of shocks (including embedded shocks) and mixed elliptic/hyperbolic crossflow.

SIMP does not require any specific form of geometry or physical grid system. The separation of the body-fitted grid calculations and the actual analysis allows the verification of the geometry before proceeding with the solution. The input consists of detailed contour geometries and environmental parameters. The output contains the surface pressure and density calculations at every marching step and detailed flow-field information at user-specified cross-section stations.

SIMP is written in FORTRAN 77 for batch execution and has been implemented on a CDC CYBER 170-series computer operating under NOS 1.4, with a central-memory requirement of approximately 260K of 60-bit words. Optional graphic output requires the PLOT10 software package. The SIMP program was developed in 1985.

This program was written by V. Shankar and K. Y. Szema of Rockwell International Corp. for **Langley Research Center**. *For further information, Circle 64 on the TSP Request Card.*
LAR-13413

Calculating Aerodynamic-Stability Derivatives

This program accommodates complicated three-dimensional shapes.

The VORSTAB program was developed to calculate the lateral-directional characteristics of nonplanar wing/body combinations in subsonic flow. VORSTAB mathematically determines the effects of edge-separated vortex flow, including augmented vortex lift, strake-induced downwash, and vortex breakdown.

VORSTAB accepts up to six lifting surfaces, under free-air or ground static conditions. Asymmetrical configurations and curved leading/trailing edges, as well as more traditional configurations, are accommodated by VORSTAB.

The computational method is based on the Prandtl-Glauert equations. VORSTAB represents the wing effect by a vortex distribution, with flow tangency solved through the quasi-vortex-lattice method. The edge-separated vortex flow is represented by Polhamus' method of suction analogy. The effect of vortex breakdown is accounted for by an empirical method. The influence of the fuselage on the flow field is modeled by vortex multiplets distributed along the body centerline.

The VORSTAB input consists chiefly of geometric specifications for the lifting surfaces, edges, flaps, and fuselage. The output includes the lateral-directional stability derivatives for both attached and vortex flow, the angle of attack for vortex breakdown at the trailing edge of a lifting surface, control effectiveness for both longitudinal and lateral-directional control surfaces, the pressure distribution, and the wing bending-moment distribution.

VORSTAB is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 170-series computer operating under NOS 1.4, with a central-memory requirement of approximately 145K of 60-bit words. The program was developed in 1984.

This program was written by C. Edward Lan of the University of Kansas Center for Research, Inc., for **Langley Research Center.** *For further information, Circle 65 on the TSP Request Card.*
LAR-13471

Wing-Design Program for Subsonic or Supersonic Speeds

The surface of mildest possible camber is generated.

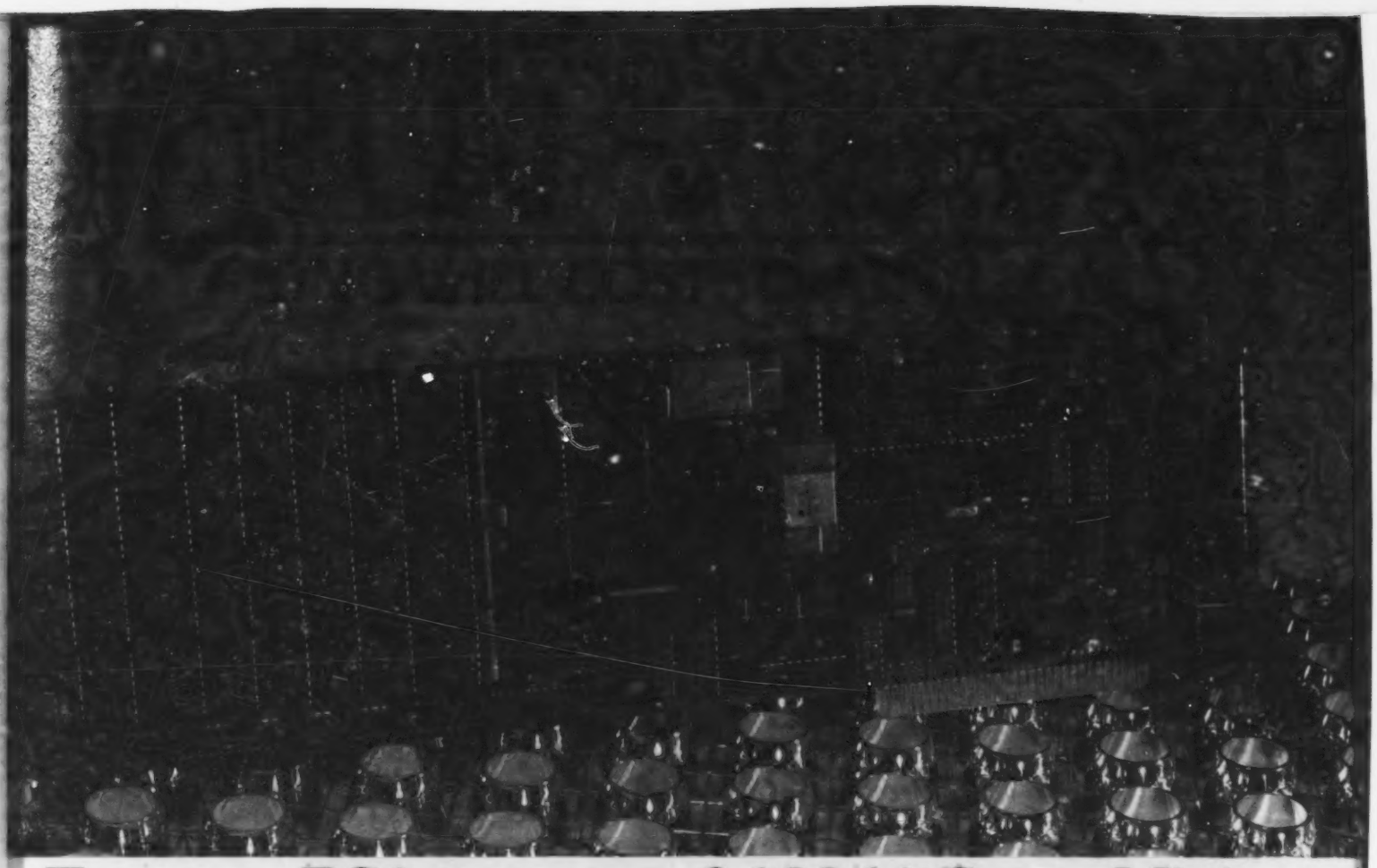
The WINGDES program provides a wing-design algorithm based on modified linear theory that takes into account the effects of attainable leading-edge thrust. A primary objective of the WINGDES approach is the generation of the surface with the mildest possible camber that will produce drag levels comparable to those attainable with full theoretical leading-edge thrust.

WINGDES provides an analysis as well as a design capability and is applicable to both subsonic and supersonic flows. The optimization can be carried out for an entire wing or for designated leading- and trailing-edge areas, for the design of mission-adaptive surfaces.

WINGDES determines an optimum combination of a series of candidate surfaces, rather than the more-commonly-used candidate loadings. An optimization procedure based on Lagrange's method of undetermined multipliers is used to select a combination of candidate surface shapes to yield minimum drag, subject to restraints on the lift and moment. The input consists of wing-planform and airfoil-section-thickness data and of such operational parameters as the mach number, Reynolds number, and design lift coefficient. The results include the optimized camber-surface ordinates, the pressure-coefficient distributions, and theoretical aerodynamic characteristics.

WINGDES is written in FORTRAN IV for batch execution and has been implemented on CDC 6600 and CDC CYBER series computers operating under NOS 1.4, with a central-memory requirement of approximately 161K of 60-bit words. The program was developed in 1984.

This program was written by Harry W. Carlson and Kenneth B. Walkley of Kentron International, Inc., for **Langley Research Center.** *For further information, Circle 66 on the TSP Request Card.*
LAR-13315



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40,000	351.50	99.71	13.13	6.38	9.07
Float Benchmark					
40,000	11.46	17.71	.83	.50	.80

Unix Benchmarks

	DSI-32	VAX 780	VAX 750
O.S. Overhead	3.88	4.4	7.0
C Compiler Test	.55	1.0	1.7
Sieve of Eratosthenes	1.93	1.7	2.4

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Circle Reader Action No. 440

Machinery

Dynamic Tooth Loads for Spur Gears

The program should facilitate the application of high-contact-ratio spur-gear concepts.

As a result of the recent interest in the possible weight saving obtained by using high-contact-ratio gear (HCRG) meshes, a computer program was developed using a time-history, interactive, closed-form solution for the dynamic tooth loads for both low- and high-contact-ratio spur gears. Because the magnitude and variation of the tooth-pair compliance with load position can affect the dynamics and loading significantly and because the tooth-root stressing per load varies significantly with load position, it was desirable to include in the dynamic gear program preprocessors and postprocessors, respectively, for calculating these two important factors. Since the tooth forms for HCRG's deviate appreciably from the tooth forms for conventional low-contact-ratio gears (LCRG's), improved and simplified methods were developed for calculating the compliance and stress sensitivity for three involute tooth forms as a function of load position — a standard LCRG tooth with no undercut and two HCRG teeth with different forms of undercut.

The method developed for calculating the compliance of spur-gear teeth follows to a great extent that developed by Weber and includes three factors: (1) the basic deflection of the tooth as a beam, (2) the deflection of the tooth caused by the fillet and foundation flexibility, and (3) the local deflection caused by the contact between the two teeth. The principal improvement in the compliance analysis was for the fillet/foundation deflection, which was found to be defined by different fillet angles for various load positions, whereas previous studies assumed a given fillet angle of about 75°. The resulting compliance analysis was evaluated by applying it to available test, finite-element, and analytic-transformation results and was found to give compliance results that agreed well with measurement and "exact" analyses.

The method developed for calculating the stress sensitivity is an improved and simplified version of the Heywood analysis. Because the tooth forms for HCRG's deviate appreciably from conventional LCRG tooth forms, the stress-sensitivity analysis had to include most of the factors affecting the stressing. The improved analysis does not assume the peak stress occurs at 30° from the base of the fillet, as the Heywood analysis does, but allows it to be a function of the load position. The sensitivity analysis was found to give results that agreed well with the Heywood and Kelley and Pederson methods, which in turn, have been found to correlate well with test results. Evaluation of the modified Heywood stress-sensitivity analysis showed that its results compared very well with available test, finite-element, and analytic-transformation results.

The formulas contained in the computer program are based on the work done by Heywood, Weber, and O'Donnell for the stress sensitivity and compliance of low- and high-contact-ratio, involute, spur-gear teeth. The parameters used in these formulas require the derivation of the effective fillet length or angle rather than assuming particular values as done by Heywood and O'Donnell. The stress-sensitivity formula is a modified version of the Heywood formula, using simple beam parameters. The compliance formula uses O'Donnell foundation-flexibility factors and Weber's local-contact compliance.

The program is written in FORTRAN IV for use on an IBM 370 computer.

This program was written by R. W. Cornell and W. W. Westervelt of United Technologies Corp. for **Lewis Research Center**. *For further information, Circle 67 on the TSP Request Card.*
LEW-14099

Fabrication Technology

Program for Heat Flow in Welding

The user can predict power requirements and temperature distributions.

This program contains a numerical model of the temperature distribution in the vicinity of a weld. The weld model can be used to produce estimated welding power requirements, welding-power-loss analysis, heat-affected-zone temperature history, and weld-puddle cross-section plots. The model can be applied to gas/tungsten-arc, plasma-arc, electron-beam, and laser-beam welds on wide plates under steady conditions.

The basic weld model combines a point source on the surface with a line source of heat. One dipole and three quadrupole components can be added at the user's option. Marangoni circulation, surface contamination, and magnetic pumping within the weld puddle can be simulated by use of the multipoles.

The entire program is written in a menu format that includes prompts for such required input as metal-characterization parameters and weld geometries. The program contains default characterization values for four common weld materials. There is extensive plotted output to the screen, including graphs of weld speed versus power, temperature versus distance from the heat source, and weld-puddle cross sections within user-defined boundaries.

The weld model is written in BASIC for interactive execution and has been implemented on a Tektronix WP 1220 series computer operating under TEK SPS with a central-memory requirement of approximately 12K of 16-bit words. This program was developed in 1984.

This program was written by A. C. Nunes, Jr., and M. H. Graham of **Marshall Space Flight Center.** *For further information, Circle 10 on the TSP Request Card.*
MFS-28081

Mathematics & Information Sciences

Program for Generating Graphs and Charts

The user can create and maintain a customized data base and related graphics.

The Office Automation Pilot (OAP) Graphics Database system offers the IBM personal computer user assistance in producing a wide variety of graphs and charts and a convenient data-base system, called a chart base, for creating and maintaining data associated with the graphs and charts. Thirteen different graphics packages are available to the OAP user. Access to each of the graphics capabilities is obtained in a similar manner. The user chooses creation, revision, or chartbase-maintenance options from an initial menu. The user may then enter or modify data displayed on a graphic chart.

The cursor moves through the chart in a "circular" fashion to facilitate data entries and changes. Various "help" functions and onscreen instructions are available to aid the user. The user data are used to generate the graphical portion of the

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Circle Reader Action No. 313

chart. Completed charts may be displayed in monotone or color, printed, stored in the chart base on the personal computer, or uploaded to an IBM host computer (if the user's personal computer supports communications).

The thirteen graphics capabilities are divided into three groups: forms, structured charts, and block diagrams. There are eight forms available: (1) bar/line charts, (2) pie charts, (3) milestone charts, (4) resources charts, (5) earned-value analysis charts, (6) progress/effort charts, (7) travel/training charts, and (8) trend-analysis charts. There are three structured charts available: (1) bullet charts, (2) organization charts, and (3) work breakdown structure (WBS) charts. There are two block diagrams available: (1) N × N charts and (2) PERT charts.

Each graphics capability supports a chart base. The OAP graphics data-base system provides the user with an effective means of managing data, which are best interpreted as graphical displays.

The OAP graphics data-base system is written in Microsoft PASCAL for interactive execution on an IBM personal or XT computer with at least 192K of memory, at least one disk drive, and the color graphic adapter and monitor. For printed charts, an Epson printer (or equivalent) is required. Source code for the entire system is available to the user for modification and customizing. An executable disk is also supplied for each of the thirteen graphics capabilities. The system was developed in 1983.

This system was developed by Clarence T. Ackerson of **Goddard Space Flight Center.** *For further information, Circle 32 on the TSP Request Card.*
GSC-12925

Scanning Program

A user can extract tokens from character strings.

The SCAN program uses a scanning algorithm to locate tokens in a line of input data. The tokens can be command words, numbers, data values, labels, and the like. By using the SCAN subroutines, a user can extract tokens from character strings in languages with simple or complex syntax. SCAN has been thoroughly tested and is implemented in NASA's Descent Design System for the Shuttle orbiter. Due to its generality, SCAN should be useful for other programs requiring input scanning.

The SCAN algorithm was developed from digital design concepts and automata theory. The program has three main elements: (1) input and output data, (2) process-control data consisting of a state value and a transition table defining the states for each category of input character, and (3) process logic.

The process logic will retrieve a character, determine the category of the character (letter, digit, delimiter, and the like), use the transition table to assign a new state, and initiate a subprocess, which depends on the new state. The SCAN process accepts a character string as input and will return the leftmost token. The test driver program included with the SCAN subroutine incorporates a loop to extract all tokens in the input line.

SCAN is written in FORTRAN 77 for interactive or batch execution and has been implemented on an HP 9000-series computer operating under UNIX 3.0 with a central-memory requirement of approximately 107K of 8-bit bytes. This program was developed in 1984.

This program was written by William C. Mattison of OAO Corp. for **Johnson Space Center.** *For further information, Circle 30 on the TSP Request Card.*
MSC-20904

Collector-Output Analysis Program

Cross-reference indexes and supplemental information are produced.

The Collector-Output Analysis Program (COAP) is a programmer's aid for analyzing the output produced by the UNIVAC collector (MAP processor). COAP was developed to aid in the design of segmentation structures for programs with large memory requirements and numerous elements but is of value in understanding the relationships among the components of any program.

COAP provides a comprehensive set of alphabetized cross-reference tables describing the relationship between elements, external references, external symbols, common blocks, and collector-defined tags. Supplemental information concerning memory requirements and allocation, common banks, undefined external references, unused elements, and unused external symbols is also provided. COAP input consists of a file containing the L-option collector print listing. If this file also contains the R-option collections of a segmented program, information on each of the relocatable elements is provided.

COAP is written in FORTRAN 77 for batch execution and has been implemented on a UNIVAC 1100-series computer operating under EXEC 8 with a central-memory requirement of approximately 65K of 36-bit words. This program was developed in 1984.

This program was written by Dave R. Glandorf and Robert F. Phillips II, of Lockheed Engineering and Management Services Co., Inc., for **Johnson Space Center.** *For further information, Circle 75 on the TSP Request Card.*
MSC-20866

Language and Program for Documenting Software Design

Accurate records are kept, and errors are detected more readily.

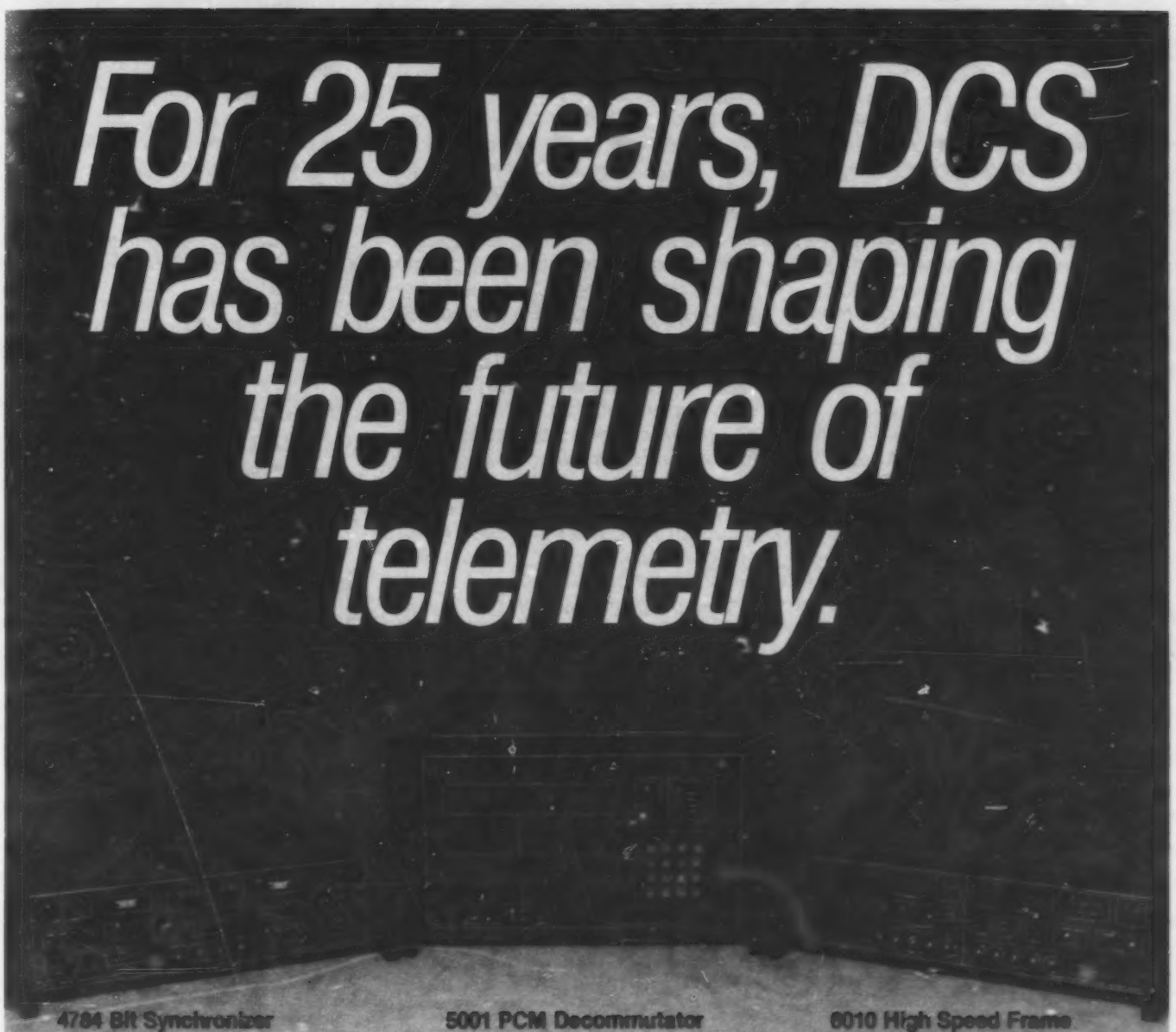
Effective, efficient communication is an essential element of the software development process. The Software Design and Documentation Language (SDDL) provides an effective communication medium to support the design and documentation of complex software applications. SDDL supports communication among all the members of a software-design team and provides for the production of informative documentation on the design effort.

Even when an entire development task is performed by one individual, it is important to document communication explicitly among the various aspects of the design effort, including concept development, program specification, program development, and program maintenance. SDDL ensures that accurate documentation will be available throughout the entire software life cycle. SDDL offers an extremely valuable capability for the design and documentation of complex programming efforts ranging from scientific and engineering applications to data management and business systems.

Throughout the development of a software design, the SDDL-generated software-design document always represents the definitive word on the current status of the continuing, dynamic design/development process. The document is easily updated and readily accessible in a familiar, informative form to all members of the development team. This makes the software-design document an effective instrument for reconciling misunderstandings and disagreements in the development of design specifications, engineering-support concepts, and the software design itself.

Use of the SDDL-generated document to analyze the design makes it possible to eliminate many errors that might not be detected until coding and testing are attempted. The SDDL processor program translates the designer's creative thinking into an effective document for

For 25 years, DCS has been shaping the future of telemetry.



4784 Bit Synchronizer

- IEEE-488 interface
- Soft decision AGC
- 10 MBPS Operation
- 1 DB of theoretical
- Card changeable for later upgrades
- Remote terminal or computer entry

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The DCS model 4784 PCM Bit Synchronizer is an upgraded version of an already proven design. This state-of-the-art telemetry data processing component is capable of handling serial PCM bit streams which have been degraded by noise, base line instabilities, or jitter. The 4784 utilizes a synchronous clock to reconstruct and normalize data to NRZ-L. Both filter/sample and integrate/reset detection techniques are available, providing optimum performance under varying operating conditions.

5001 PCM Decommutator

- Multiple program format storage
- Programmable bit synchronizer
- Integral PCM simulator
- Diagnostic self-test
- Remote terminal or computer entry

We continue to pioneer better ways to serve our customers.
The DCS model 5001 PCM Decommutator utilizes the most recent developments in microprocessor technology, and brings these capabilities to the field of high bit rate PCM. A dedicated microprocessor within the Decommutator interfaces with a front panel keyboard and a 16-digit alpha/numeric display. The panel displays program parameters, or data, under control of the keyboard. Up to 30 formats may be saved in nonvolatile storage.

At DCS, we always support our customers with fast, on-call maintenance in your shop or ours.

6010 High Speed Frame Synchronizer

- 30 MBPS bit rate
- ECL technology
- Adaptive pattern recognition
- Auto polarity recognition

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The DCS model 6010 High Speed PCM Frame Synchronizer represents one of the most technologically advanced instruments of its kind in the industry today. It is capable of handling data rates of up to 30 MBPS utilizing an adaptive frame sync strategy consisting of search, check, and lock; based on four sequential, correct and incorrect patterns. Auto polarity inverts the incoming data when a compliment of the frame synchronization pattern is detected. The 6010 and soon to be released, 4785 Bit Synchronizer are the forerunners of a whole new family of products now in advanced stages of design.

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Circle Reader Action No. 371

communication. The processor performs as many automatic functions as possible, thereby freeing the designer's energy for the creative effort.

Document formatting includes graphical highlighting of structure logic, the accentuation of structure escapes and module invocations, logic-error detection, and special handling of title pages and text segments. The SDDL-generated document contains software-design summary information, including module-invocation hierarchy, module cross-reference, and cross-reference tables of user-selected words or phrases appearing in the document.

The basic forms of the method are module and block structures and the module-invocation statement. A design is stated in terms of modules that represent problem abstractions that are complete and independent enough to be treated as separate problem entities. Blocks are lower level structures used to build the modules. Each of both kinds of structure may have an initiator part, a terminator part, an escape segment, or a substructure.

The SDDL processor program is written in PASCAL for batch execution on an IBM 370-series computer under OS. The PASCAL version of SDDL was developed in 1981 and last updated in 1984.

This program was written by Henry Kleine and Thomas M. Zepko of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 70 on the TSP Request Card.*
NPO-16511

Fitting Polynomial Equations to Curves and Surfaces

A program finds least-squares fits for functions of two independent variables.

FIT is a computer program for interactively determining least-squares polynomial equations that fit user-supplied data. FIT will approximate a given y = f(x) with a polynomial and plot the resulting curve. FIT also includes a method for computing the polynomial equation of a surface fit to data that are described by a function of two independent variables, y = f(x,z). Computer graphics are provided to allow the user to evaluate the shape characteristics of the calculated fit. The interactive graphical and editing capabilities in FIT enable the user to control the polynomial equations to be fitted to data arising from most practical applications.

FIT requires data values for the dependent variable y and the independent variable x (also z for surface fits). A weighted-least-squares solution determines the polynomial coefficients for the independent variable x. For surface fits or "crossplots" of two variables, the calculated x coefficients are then treated as dependent-variable values across z.

The user can specify the order of polynomial; alter weighting factors; edit the input data; view customized plots with defined labels, grids, reference lines, and scaling; and save the plotting parameters in a file for future use. FIT is menu-driven and includes a HELP facility.

FIT is written in FORTRAN and COMPASS for interactive execution and has been implemented on a CDC CYBER 170-series computer operating under NOS with a central-memory requirement of approximately 146K (octal) of 60-bit words. FIT requires a Tektronix terminal with PLOT-10 software to support its full graphics capability. This program was developed in 1984.

This program was written by P. Douglas Arbuckle, Steven M. Sliwa, and Sherwood H. Tiffany of **Langley Research Center** *and Marie-Louise Roy of Kentron International, Inc. For further information, Circle 36 on the TSP Request Card.*
LAR-13457

Structured Design Language for Computer Programs

This language can be used at all stages of program development.

The BOX language was developed to provide for improved productivity in designing, coding, and maintaining computer programs. BOX is a structured design language that can be used from the earliest conceptual design stage through the final coding.

At the design stage, comments are used to define the logical structure of the code in terms of functional boxes. In the coding stage, statements from an intermediate language like FORTRAN are used to implement the functions described in the comments, and condition lines are added to relate the required logic to program variables. The branching logic required by the structures is automatically generated from these conditional lines and the comments that define the structures. The usual FOR, WHILE, and UNTIL loops and the IF-THEN-ELSE and CASE structures are implemented in a consistent and explicit way.

The BOX system is written in FORTRAN 77 for batch execution and has been implemented on an HP 9000 series computer operating under HP-UX. The current BOX system uses FORTRAN 77 as the intermediate language. The BOX system was developed in 1982 and last updated in 1985.

This program was written by Walter H. Pace, Jr., of TRW, Inc., for **Johnson Space Center.** *For further information, Circle 31 on the TSP Request Card.*
MSC-20917

Workspace Program for Complex-Number Arithmetic

The existing APL language is empowered to manipulate complex numbers.

Complex-variable methods provide analytical tools invaluable for applications in mathematics, science, and engineering. The advent of computers significantly streamlined the bulk of manipulations involved in complex-number methods. APL is a computer-programming language with powerful matrix-handling capabilities, but it has no built-in complex-arithmetic functions. COMPLEX is a workspace program designed to empower APL with complex-number capabilities.

Functions available in COMPLEX include addition, subtraction, multiplication, and division; trigonometric and hyperbolic functions; natural and general logarithms; and such other functions as power, root, and modulus. Still other functions can be programmed by building on existing functions.

A program is converted to complex-number arithmetic by replacing +, −, ×, ÷, etc., with the appropriate COMPLEX operators. The user assigns complex values to the desired variables, usually in a matrix of 2*N, where N is the number of complex variables.

COMPLEX is written in APL for use with interactive or batch programs and has been implemented on a Honeywell Sigma-series computer operating under CP-V with a central-memory requirement of approximately 6K bytes. This workspace program was developed in 1985.

This program was written by Marshall C. Patrick and Leonard W. Howell, Jr., of **Marshall Space Flight Center.** *For further information, Circle 23 on the TSP Request Card.*
MFS-28111

Estimating Prices of Products

Company-wide or process-wide production can be simulated.

The Improved Price Estimation Guidelines (IPEG) program provides a simple yet accurate estimate of the price of a manufactured product. The IPEG program facilitates sensitivity studies of price estimates at considerably less expense than would be incurred by the Standard Assembly-line Manufacturing Industry Simulation, SAMIS, program [see "Solar Array Manufacturing Industry Simulation" on page 446 of *NASA Tech Briefs*, Vol. 4, No. 3, Fall 1979 (NPO-14747)]. A difference of less than 1 percent between the IPEG and SAMIS price estimates has been observed with realistic test cases.

The IPEG simplification of SAMIS allows the analyst with limited time and computing resources to perform a greater number of sensitivity studies than with SAMIS. Although the IPEG program was developed for the photovoltaic industry, it is readily adaptable to any standard assembly-line type of manufacturing industry.

The IPEG program estimates the annual production price per unit. The input data include the costs of equipment, space, labor, materials, supplies, and utilities. Production on a company-wide basis or a process-wide basis can be simulated. The IPEG input file can be generated by SAMIS or may be prepared by the user. Once the IPEG input file is prepared, the original price is estimated, and sensitivity studies may be performed.

The IPEG user selects a sensitivity variable and a set of values. IPEG will compute a price estimate and a variety of other cost parameters for every specified value of the sensitivity variable. The IPEG program is designed as an interactive system; it prompts the user for all required information and offers a variety of output options.

The original IPEG program is written in SIMSCRIPT II.5 for interactive execution and has been implemented on an IBM 370-series computer with a central-memory requirement of approximately 300K of 8-bit bytes. The original IPEG program was developed in 1980. The IPEG/PC program is written in TURBO PASCAL for execution on an IBM PC computer under DOS 2.0 or above with at least 64K of memory. The IBM PC color display and color graphics adapter are needed to use the plotting capabilities in IPEG/PC. The IPEG/PC program was developed in 1984.

This program was written by Robert W. Aster, Robert G. Chamberlain, Silvino C. Zendejas, Thomas S. Lee, and Shan Malhotra of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information Circle 4 on the TSP Request Card.*
NPO-16583

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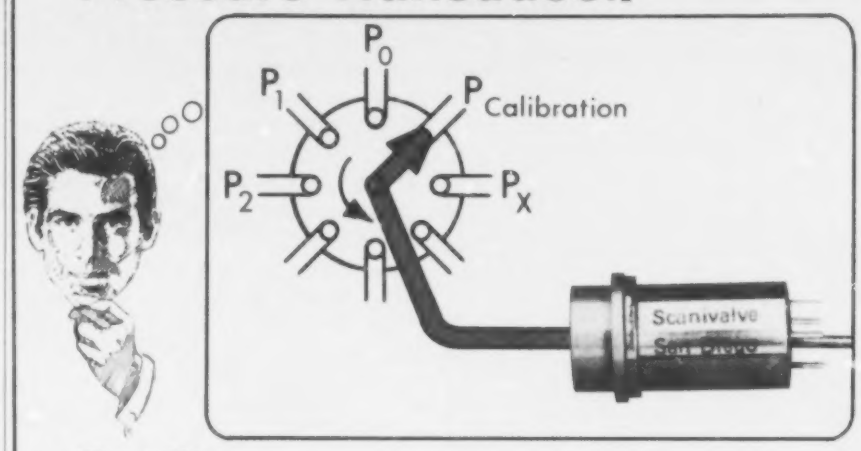

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While there is no "Self-Calibrating" pressure transducer, this ideal can be closely approached through the use of Scanivalve® pressure scanning systems.

Scanivalves® time-share a single high quality pressure transducer with up to 64 unknown pressures, and are configured to AUTOMATICALLY CALIBRATE the transducer on every data scan. Complete Scanivalve® systems are capable of scanning as many as 768 inputs (either pressure or electrical) at rates as high as 120 points per second. All Scanivalves® are easily interfaced to host computers via either RS-232C or IEEE-488. Scanivalves® offer outstanding reliability; many Scanivalve® systems have been in continuous operation for over 20 years without failure. This remarkable performance is accompanied by high accuracy (0.06% full scale), and low cost (approx. $50.00 per input).

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84 **Omnivector Probe Measures Airflow**
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Ultrasonic Inspection Near Small Bores

A portable, lightweight instrument finds small cracks near internal surfaces.

Marshall Space Flight Center, Alabama

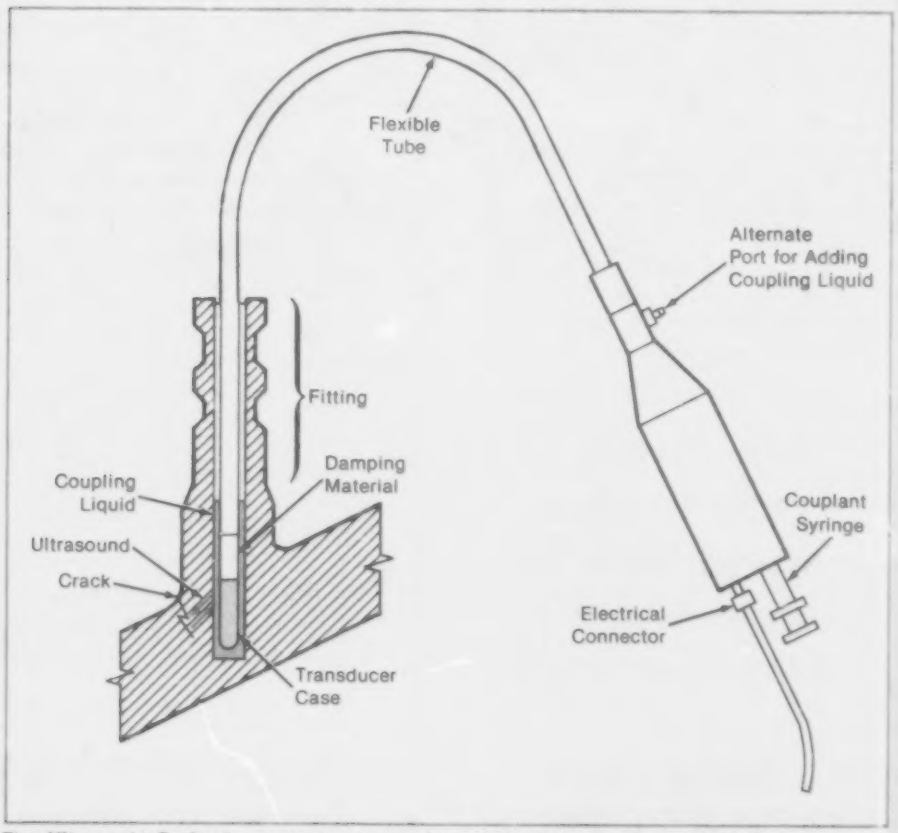
A portable ultrasonic probe makes it possible to inspect for hidden cracks near the insides of narrow tubes. Using the pulse-echo technique, the instrument can detect cracks as small as 0.015-in. (0.38-mm) deep. It can be used for nondestructive inspection of other hard-to-reach places where conventional large transducers will not fit or where it is difficult to apply coupling liquid for contact ultrasonic testing.

The probe is connected to conventional ultrasonic inspection equipment through a flexible tube. The probe and tube are inserted in the part to be inspected (see figure). At its tip, the probe holds an ultrasonic transducer — a piezoelectric crystal in a stainless-steel case. The case centers the crystal in the part to be inspected and dispenses acoustic coupling liquid from orifices. A damping material isolates the transducer acoustically from the probe tube. The probe tip and the damping material are made of Emerson and Cuming resin 2057 (or equivalent) cured with Catalyst 9 (or equivalent).

The probe tube, made of polytetrafluoroethylene or a similar material, can bend around corners in the part. It carries coupling liquid from the probe handle to the transducer and serves as a conduit for electrical wires between the transducer and the external ultrasonic equipment. Coupling liquid is supplied through a port in the handle from a syringe or from a pressurized line. The diameter of the transducer is tailored to the size of tube under inspection.

After inserting the probe in the part, the test operator pushes the syringe plunger on the handle to inject the coupling liquid. The operator then slowly withdraws the probe while rotating it, thereby ultrasonically scanning the inside wall over the length of the tube.

This work was done by Ronald G. Parent of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29024



The **Ultrasonic Probe Inspects** the bore of a tubelike fitting. The ultrasonic instrument makes it unnecessary to disassemble the fitting to check for cracks. A precise orientation of the transducer with respect to the part is not necessary for detecting cracks.

Capture the Glory!

Now you can own this collector's print, commemorating Columbia's exploits, at an exceptional introductory price.

Noted aviation artist Ken Kotik has captured *Columbia* in all its glory to commemorate the completion of four test flights and the first operational mission, STS-5. This fine print—truly a collector's item—depicts the orbiter in full color, side view, with every feature crisply detailed.

Arranged beneath the ship, also in full color, are the five distinctive mission patches. But what makes Ken Kotik's work most unique is his method of creating a 'historical panorama' via individual vignettes surrounding the side view of *Columbia*.

Educational as well as eye-appealing, these scenes, which are expertly rendered in a wash technique, include such subjects as the orbiter under construction at Rockwell, on the launch pad, at touch-down and during transit on its 747 carrier. Concise copy, hand-written by the artist, accompanies each vignette. (*Important:* The greatly reduced print reproduced here is intended only to show style—at the full 32" by 24" size, all copy is clearly readable.)

About the artist.

Ken Kotik, a 37-year old Colorado native, has been a professional commercial artist for the past 14 years. In his own words, he "eats, drinks and sleeps flying." It shows in the obvious care and attention he brings to each print or mural. When not at his drawing board creating artworks for such prestigious institutions as the Air Force Academy, Ken can be found at the controls of his Schweitzer sailplane, in which he competes nationally. A self-taught artist, he specializes in airbrush-applied acrylic techniques. *Space Shuttle Columbia: The Pathfinder* is his first work on the space program, and the original art has been accepted by the Smithsonian Air and Space Museum for its permanent collection.

About the artwork.

Space Shuttle Columbia: The Pathfinder was printed in five colors, after individual press proving, on exhibit-quality 80 lb text 'Hopper Feltweave' textured paper. The feltweave texture yields properties most desirable for framing and display.

About ordering.

Each *Columbia* print comes packed in a sturdy mailing tube and will be shipped upon receipt of your order at the introductory price of $9.95. Please allow two to three weeks for delivery. There is a one-time *first class* postage and handling charge of $2.50 for each order. (If you order three prints, for example, you still include only $2.50 for postage and handling to cover the entire order.) To ensure that you receive your prints without delay, fill out and mail the coupon today, *including check or money order only* and local tax where applicable. If coupon has been clipped, mail your order to: NASA Tech Briefs, Columbia Print Offer, 41 E. 42nd St., New York, N.Y. 10017.

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Please rush _____ Columbia prints.
I have enclosed $_____ plus $2.50 for *first class* postage and handling.
Total enclosed: $_____.

Name _____

Address _____

City _____ State _____ Zip _____

New York State residents add 7% sales tax
New York City residents add 8.75% sales tax

☐ Please add my name to your mailing list for future print offerings. SS-1

Beta Backscatter Measures the Hardness of Rubber

Specimens can be thinner than those used on conventional mechanical testers.

Lyndon B. Johnson Space Center, Houston, Texas

A nondestructive testing method determines the hardness, on the Shore scale, of room-temperature-vulcanizing silicone rubber. The method measures backscattered beta particles; the backscattered radiation count is directly proportional to the Shore hardness.

Ordinarily, a durometer is used to measure the Shore hardness of a resilient material. However, reliable durometer measurements can be made only when the specimen is at least 0.25 in. (6.4 mm) thick. The backscatter technique can be used on specimens as thin as 0.02 in. (0.5 mm). For example, it might be used to test the postcure hardness of thin silicone rubber gaskets and seals.

The backscatter-measuring system includes a thallium-204 beta-particle emitter, a Geiger-Müller tube, a test stand, and a computer for data processing and control. The emitter is housed in a platen and is encased, with the tube, in the upper part of the test stand (see figure). When the test stand is placed on the rubber specimen, its weight makes the rubber bulge into the slot in the apex of the platen. The amount of bulging increases as the hardness of the rubber decreases.

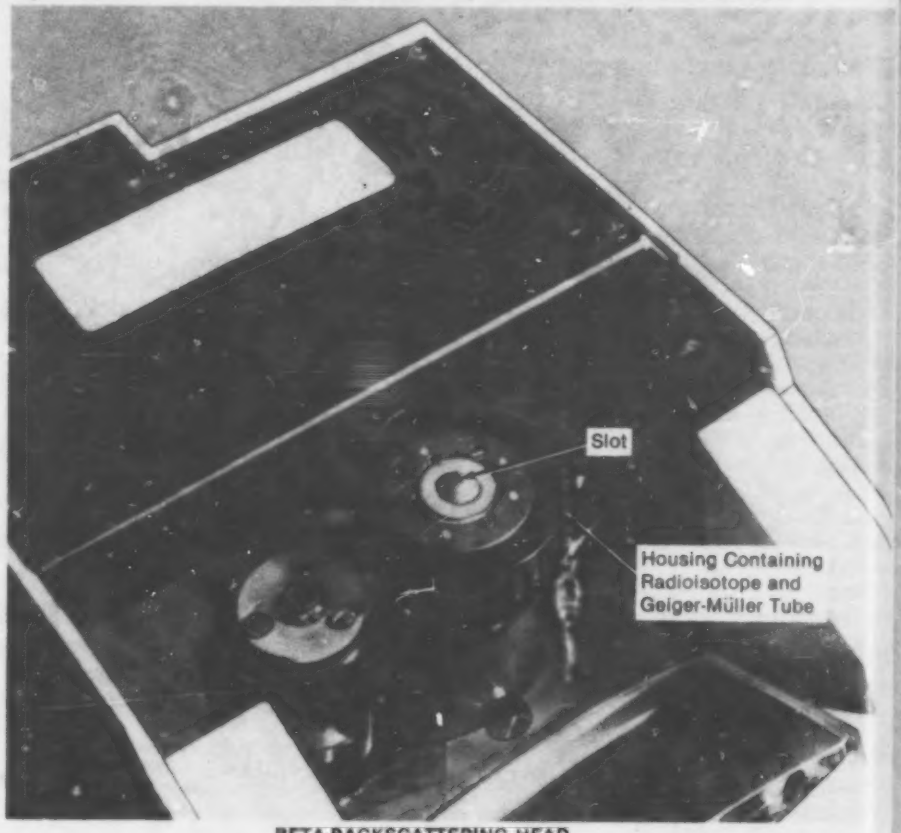
Beta particles from the thallium isotope pass through the slot and bombard the specimen. The Geiger-Müller tube detects the radiation scattered back from the specimen. The more the specimen bulges, the more it directs the backscattering away from the Geiger-Müller tube and the fewer the radiation counts recorded. Conversely, the greater the hardness, the greater the radiation count. The relationship between the hardness and the Geiger-Müller count rate is nearly linear except at very low rates.

The test set is calibrated with a specimen, the Shore hardness of which is known from a mechanical durometer test. Then a specimen of unknown hardness is tested, and its radiation count is recorded. The count is compared with that for the known sample to find the Shore hardness of the unknown.

This work was done by Edward T. Morrissey and Frank N. Roje of Rockwell International Corp. for **Johnson Space Center**. *For further information, Circle 78 on the TSP Request Card.*
MSC-20991

TESTING SYSTEM WITH SAMPLE IN PLACE

The Hardness Test Setup consists of a commercial beta-backscattering system. The backscattering technique is usually used to measure the thicknesses and compositions of coatings on the basis of chemical properties. Here, it is used to measure hardness.



BETA-BACKSCATTERING HEAD
(Turned Upside Down for Visibility)

The Inland Motor Team Philosophy: Enhance While Simplifying—Specify Direct-Drive.

Inland Motor is the original manufacturer of direct-drive, frameless, DC torque motors. Although we've been providing these high-performance motion control solutions for more than 30 years, many designers don't fully realize the principles behind these motors—or their remarkable potential.

All Parts Dedicated To Motion

As illustrated in Figure 1, a direct-drive, frameless motor has no housing, no shaft and no bearings. It's comprised of three major components: stator, rotor and brush-ring (or sensor assembly for brushless motors). A frameless motor becomes an integral part of the host machine and relies upon the existing bearing structure for its support. Often, the unusual geometry—and extraordinary performance—of a frameless motor is the only solution to a challenging motion control problem.

Direct-drive motors eliminate the unwanted backlash, cogging and compliance associated with the gears, belts and couplings used in non-direct systems. This *direct* attachment of the frameless motor allows the designer to apply torque precisely where it is needed in the mechanism, rather than at some remote location.

Direct-drive motors have very high torque-to-inertia ratios *at the load*—where it really counts. The ratio indicates how responsive the system will be to commands for rapid stops and starts. In a geared system, the reflected torque is proportional to the gear ratio while inertia is reflected as the square of the gear ratio. One clear advantage of direct-drive motors is a torque-to-inertia ratio better by a factor equal to the gear ratio under consideration.

Designed To Be Predictable

Our DC torque motors are designed to be predictable. (See Figure 2.) We go to great lengths to preserve linearity over the full range of operation. From the lowest excitation through peak level, output torque is directly linear with respect to current load. Thus, stability and response criteria do not change with respect to load.

Plus, frameless DC motors grant economy of space. We use the finest magnetic materials when designing our motors, which allows us to pack a great deal of "muscle" into a very small package. Furthermore, since the motor rests on existing bearings and shaft, redundant parts are eliminated.

Figure 1 shows that frameless motors have a hole through their center. For many customers, this space is crucial for cable runs, waveguides or optics. Frameless motors free up the center axis so it can be used for other purposes.

Selection of a Direct-Drive Motor

Direct-drive motors often operate near to zero speeds as they precisely control positon or angular rate. For this reason, these unique motors cannot be measured by conventional standards such as horsepower. Rather, the primary figures of comparison for torque motors are peak torque, motor constant and physical size. The following criteria are the basis on which our engineers can quickly define a motor suitable for your requirements.

Maximum Torque—sum of all torque seen by the motor, encompasses acceleration torque, friction, windage and viscous losses.
Maximum Speed.
Maximum Power Point—where the highest product of torque and simultaneous speed occur.
Duty Cycle.
Power Budget—available DC voltage and current.

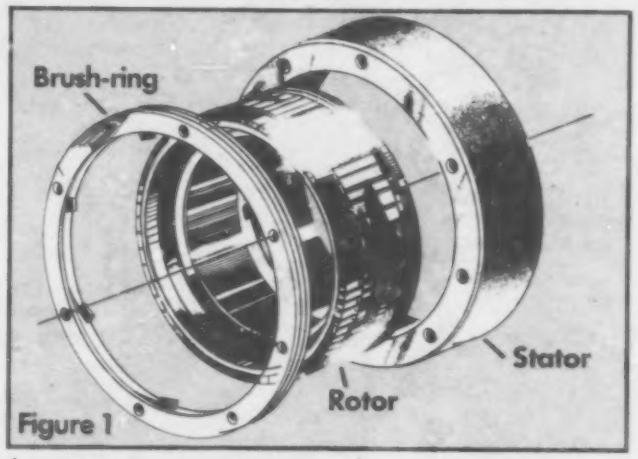


Figure 1

Ambient Temperature.
Operating Environment.
Size Restrictions—allowed O.D., I.D. and axial length.

Send Us Your Most Un-Controllable Problems

Inland Motor Specialty Products Group: a team of people committed to delivering solutions to your most challenging motion control problems. Let us show you how responsive our direct-drive motors—and our organization—can be.

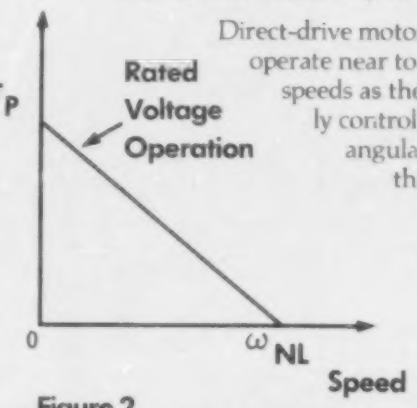


Figure 2

INLAND MOTOR
KOLLMORGEN CORPORATION

SPECIALTY PRODUCTS GROUP
501 First St. Radford, VA 24141
703/639-9045 TWX: 710-875-3740

Circle Reader Action No. 423

Omnivector Probe Measures Airflow

The probe outputs are direct measures of perpendicular velocity components.

Lewis Research Center, Cleveland, Ohio

A probe (called an omnivector anemometer) has been designed and tested that has a fixed-position sensing element capable of simultaneously measuring steady and unsteady velocity head and flow direction of a moving fluid over a complete 360-degree angle in two-dimensional flow.

One of the problems in experimental fluid mechanics is the difficulty of providing flow probes capable of operating over a wide range of flow direction, including flow reversals. In some situations (such as stall and surge of jet-engine compressors), changes in flow direction take place very rapidly. These problems have been overcome with the development of this new omnivector anemometer.

The sensing element of the omnivector anemometer (as shown in Figure 1) is mounted on the end of a support tube, which is necessary for inserting the sensing element into the flow field. The main element of the anemometer is a drag body consisting of a cylindrical tube upon which are mounted eight miniature strain gages near the base and electrically connected in the form of two four-arm Wheatstone bridges (see cross section A-A). The strain gages, which form the arms of the two bridges, are arranged around the tube so as to provide the X and Y components of the drag force due to the moving fluid. The square root of the sum of the squares of the output of the bridges (E_1 and E_2) is proportional to the velocity head (one half times the fluid density times the square of the fluid velocity), and the ratio of the two outputs (E_2/E_1) is the tangent of the flow angle, Θ, (see Figure 2). If the variation in fluid density is negligible, the fluid velocity may be obtained from the computed value of the velocity head.

The natural frequency of the probe tested (sensing element length of 500 mm, wall thickness of 0.1 mm, and with a 1.5-mm-thick end cap) was 1.5 kHz, so the probe can be used for unsteady measurements to about 0.5 kHz.

This work was done by L. N. Krause and G. C. Fralick of **Lewis Research Center.** *No further documentation is available.*
LEW-13830

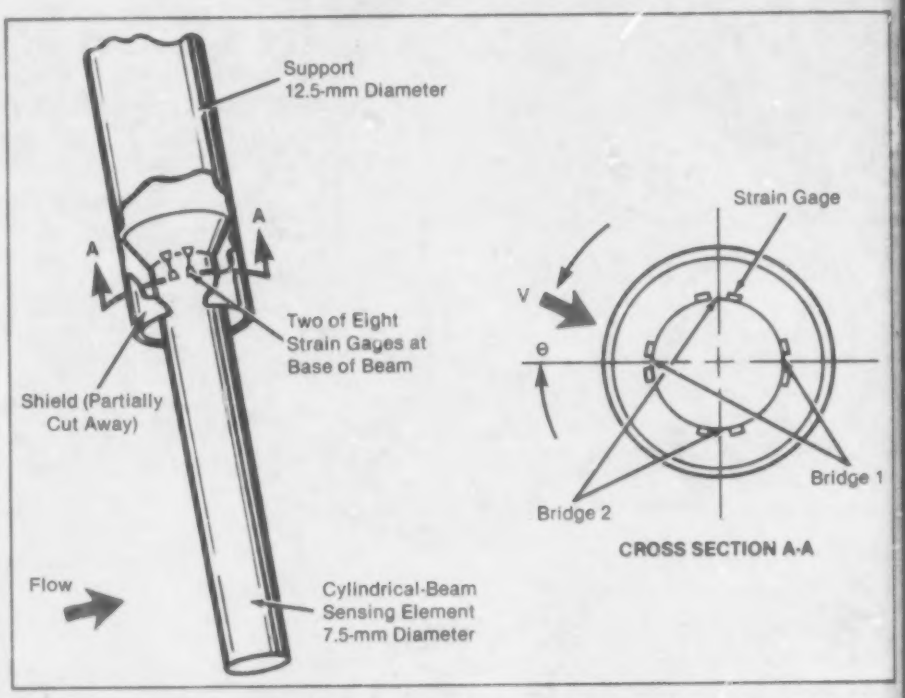


Figure 1. The **Omnivector Anemometer** includes a cylindrical sensing element with eight strain gages. The gages, connected in two Wheatstone bridges, sense the two perpendicular components of flow across the cylinder.

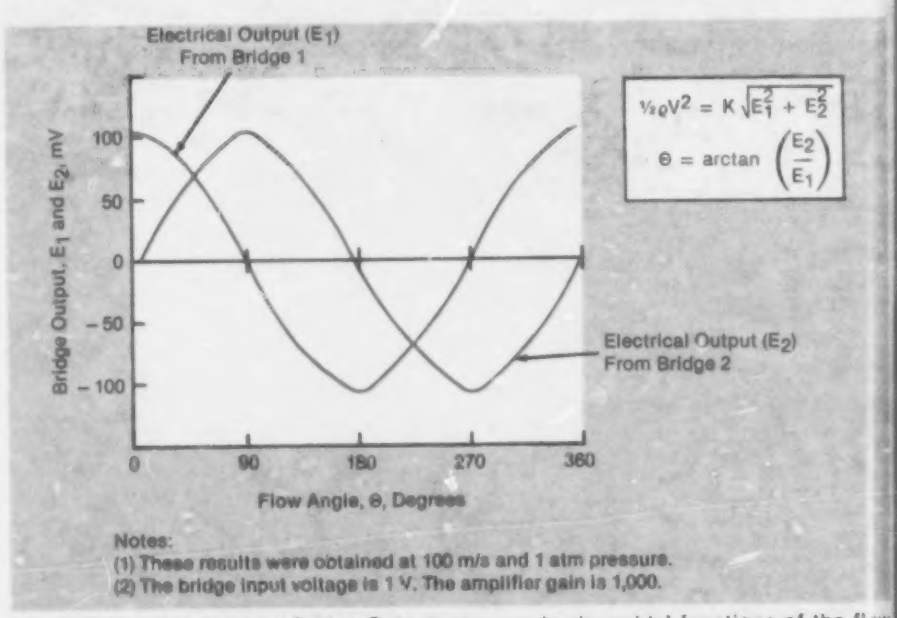
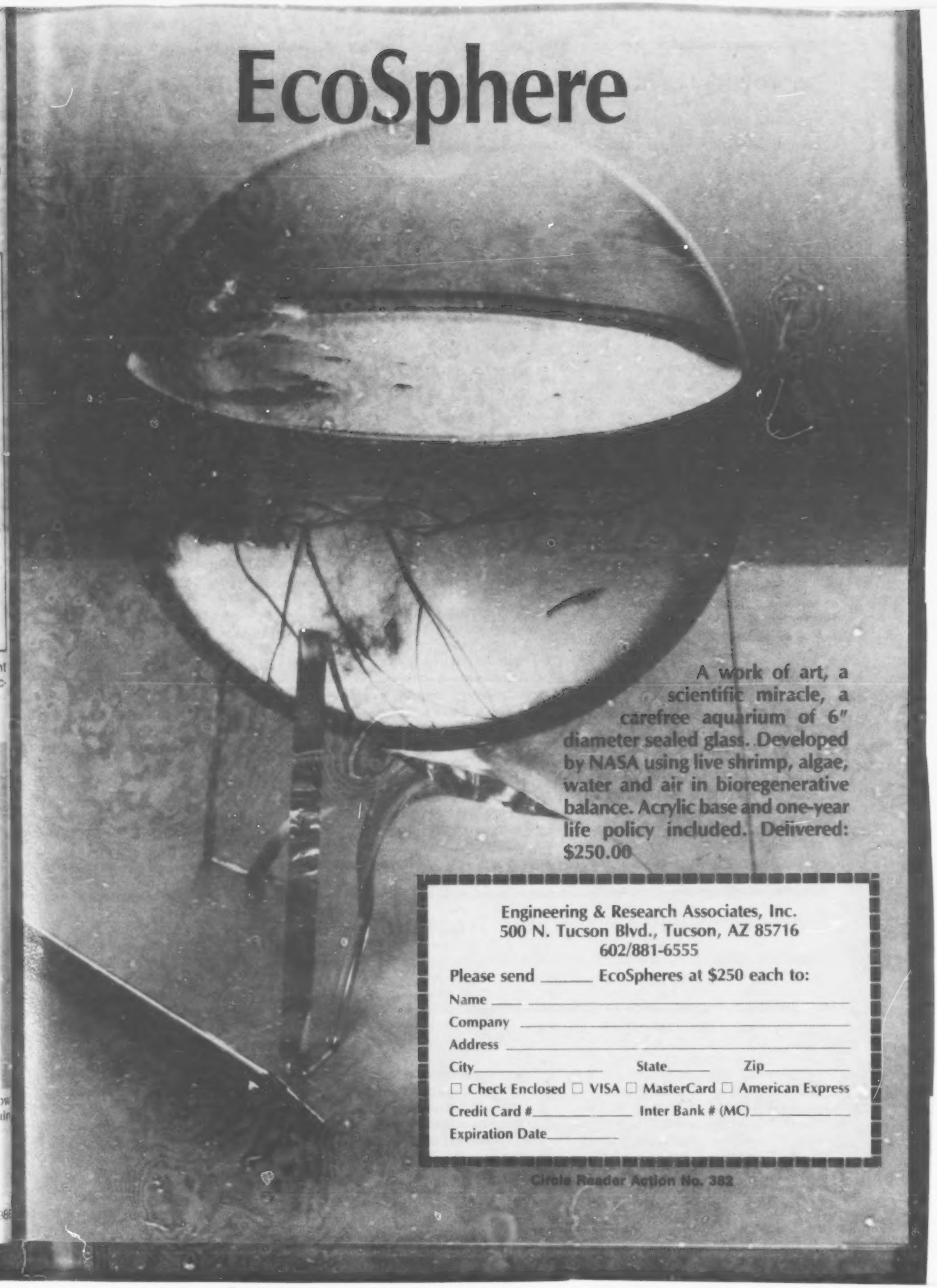


Figure 2. The **Anemometer-Bridge Outputs** are nearly sinusoidal functions of the flow angle. The outputs are therefore combined in the usual trigonometric fashion to obtain the magnitude and direction of the flow.

EcoSphere



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Circle Reader Action No. 382

Improved Technique for Finding Vibration Parameters

Filtering and sample manipulation reduce noise effects.

Lyndon B. Johnson Space Center, Houston, Texas

An analysis technique improves the extraction of vibrational frequencies and damping rates from measurements of the vibrations of a complicated structure. The technique is based on a statistical method for analyzing vibrational data but is less susceptible than an earlier version is to errors induced by noise and by the presence of multiple modes.

The structural vibrations are measured by accelerometers, the outputs of which are digitized at a frequency high enough to cover all the modes of interest. The mathematically-reconstructed vibrational acceleration, $\ddot{z}$, is expressed as a sum of N damped, sinusoidal vibrational modes, namely:

$$\ddot{z}(t) \equiv \sum_{n=1}^{N} \ddot{z}_n(x,y)\exp(-\beta_n + i\omega_n)t$$

where t is time, x and y represent spatial coordinates, and $\ddot{z}_n$, β_n, and ω_n represent the acceleration amplitude, damping coefficient, and frequency, respectively, of the nth mode. The coherence function, Γ^2, gives a measure of how closely the reconstructed and measured accelerations differ, and is expressed by

$$\Gamma^2 = 1 - \frac{\sum(\ddot{Z} - \ddot{z})^2}{\sum \ddot{Z}^2}$$

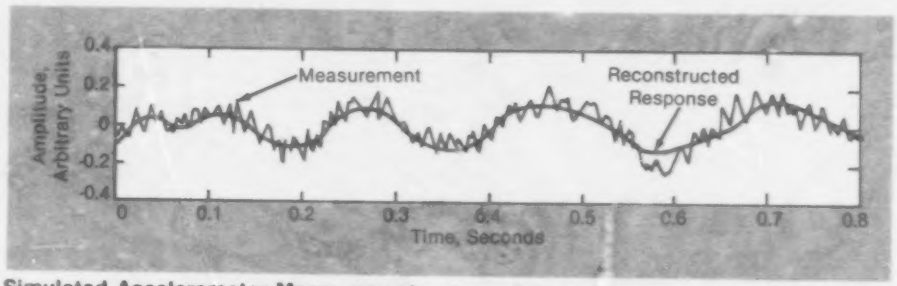
where $\ddot{Z}$ is the measured acceleration and the sum is taken over all the digitized measurements obtained during the sampling interval.

To eliminate aliased data from vibrational responses above the Nyquist frequency, the mode shapes are compared to predicted ones with natural frequencies below the maximum frequency of interest; those with low correlations are discarded. Next, pools of damping rate/vibration frequency pairs having nearly equal values (thus representing the same mode) are formed. The pairs with the highest Γ^2, mode-shape correlations, and modal confidence factors are selected for the final acceptance test.

The candidate modal components that have survived to this point are subjected to a computation of the increment of multiple coherence that occurs when each previously unaccepted component is combined with the previously accepted ones. The one that yields the highest increment is accepted. This procedure is repeated until the subsequent increments of the coherence value decrease to less than 1 percent of the previous coherence value or until all the candidate modes are accepted.

The measurement data often contain noise (see figure) and multiple simultaneous modes. While this usually poses no serious obstacle to finding the modal frequencies, it often leads to significant errors in the modal damping rates; which is unacceptable, because accurate damping rates are necessary for the prediction of flutter in large, complicated structures.

Of the various ways of processing the measurements to reduce the effects of noise, the ones that work best include digital low- or band-pass filtering, the manipulation of modal starting times, the selection of sample sizes, and combinations of these. Use of the improved method on a set of vibrational measurements from the Space Shuttle, for example, raised the level of coherence from previous values below 50 percent to values between 90 and 99 percent.



Simulated Accelerometer Measurements at a point on a structure (in this case, the Space Shuttle) were taken after an excitation at 6.25 Hz. The measurements are noisy, but the vibrational response reconstructed from the measurements shows little noise.

This work was done by Lowell V. Andrew and Charles C. Park of Rockwell International Corp. for **Johnson Space Center**. *For further information, Circle 85 on the TSP Request Card.*
MSC-20901

Synchronously Deployable Truss Structures

The structure is lightweight, readily deployed, and has reliable joints.

Langley Research Center, Hampton, Virginia

Deployable beam structures are required for many applications aboard the proposed space station as well as for uses in other artificial satellites. These structures must pack efficiently for launch into orbit and must deploy reliably upon command. A new truss concept, designated as the "pac truss," has been developed to rectify many of the shortcomings of previous designs, including the need for a complex deploying mechanism.

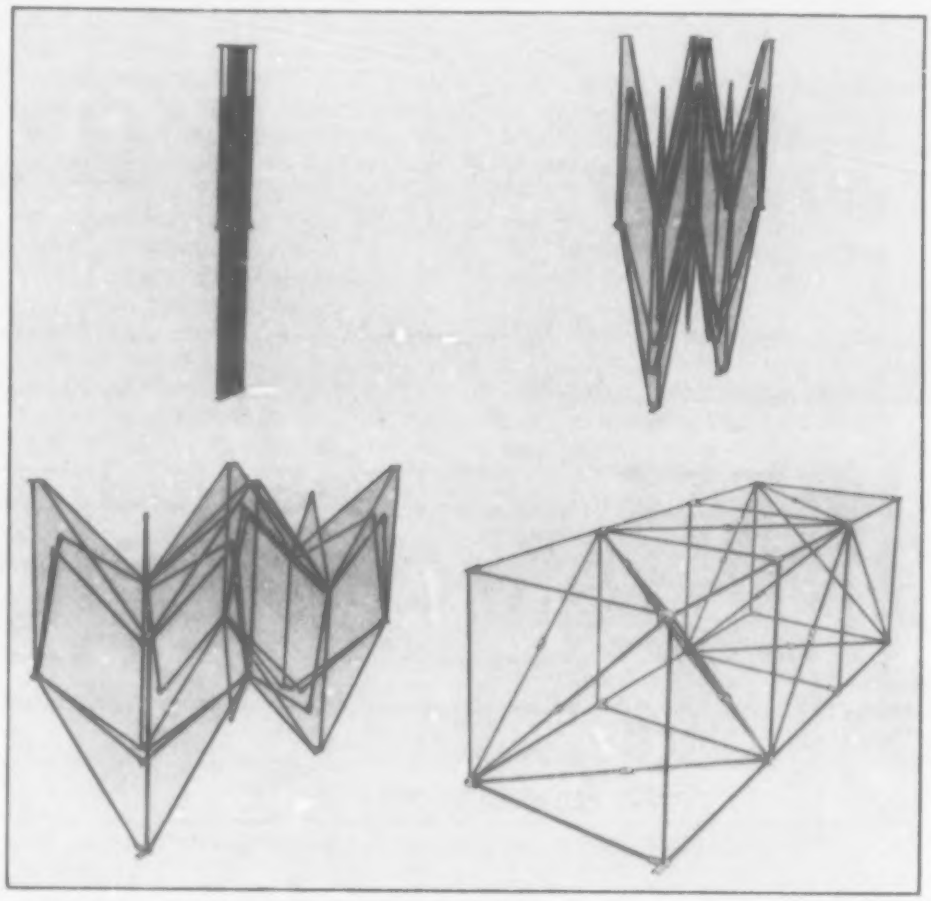
As shown in the figure, the truss beam has four longeron members located at the corners of the rectangular cross section. A series of battens and diagonals connects the longerons together at joints or nodes. The cross section is maintained by a section diagonal, and the orientations of the section diagonals alternate 90° from node to node. All members connect at nodes in such a way that only two node types are required.

For deployment, each diagonal has a midlength hinge that opens the member, permitting the diagonals and battens to rotate about simple clevis-type hinges at the nodes. The deployment of all members occurs in a synchronous manner; therefore, the beam deploys simultaneously in length and width. During deployment, the diagonal opens to the fully extended straight position, and the midlength hinge is locked by a latch, thus locking the model in the fully deployed position.

Truss-beam deployment can be accomplished by a number of methods. Since deployment is synchronous, an astronaut can deploy a long truss beam or large platform simply by hand deployment of a single bay. Also, structures of this type could be deployed in free flight by the controlled release of stored energy in torsional springs at selected hinges located throughout the structure. The same double-folding technique used in the beam model is applicable to flat planar trusses, allowing structures of large expanse to be folded into compact packages and to be deployed for space-platform applications. The unique folding arrangement of the members also permits the preattachment of instrumentation and utility cables to the longeron members without degradation of packaging or deployment.

This work was done by Marvin D. Rhodes of **Langley Research Center** *and John M. Hedgepeth of Astro Research Corp. No further documentation is available.*

Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13490.



The "Pac Truss" Features Easy Deployment without the need for complex mechanisms.

Detecting Foreign Particles in Wind Tunnels

A simple scratch test tells whether particles, which could distort results, were present in a test.

Lyndon B. Johnson Space Center, Houston, Texas

A polished metal surface is used to detect abrasive foreign particles in an airflow test chamber such as a wind tunnel. Scratches and dents from such particles are readily apparent on the metal surface. Because it is impractical, if not impossible, to filter out all foreign particles, at least the detector can be used to provide evidence of particles in cases in which they are suspected of distorting the experimental results.

The detector was developed for tests of the abrasion resistance of flexible insulation blankets. When blankets partially disintegrated in wind-tunnel tests, there was no way of knowing whether the damage was caused only by the fast airflows or was also influenced by entrained particles. Now, when a detector indicates that particles were present in a test, the results can be interpreted accordingly.

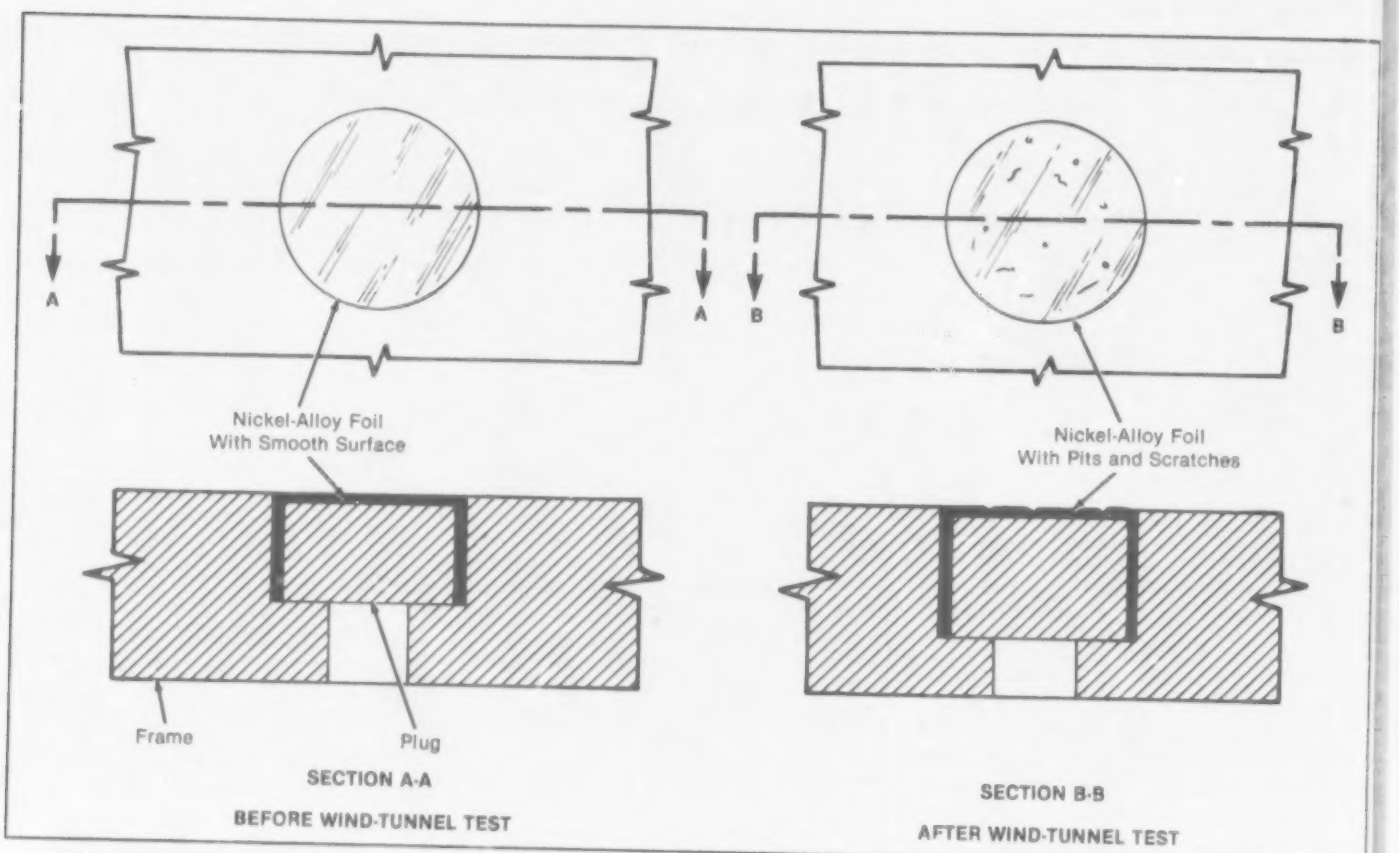
The insulation specimen to be tested is mounted in a frame made of a lightweight silica insulating material (see figure). The frame protects the edges of the specimen. The frame contains holes for the detectors. Each detector consists of a plug of the same material as that of the frame, covered by a layer of Inconel* (or equivalent) nickel-alloy foil 0.001 in. (0.025 mm) thick.

The materials in the detector plug can easily withstand high temperatures. The detector can also be used in tests of paints and coatings to determine whether abrasive particles are present.

(*Inconel is a registered trademark of the Inco family of companies.)

This work was done by Howard L. Sharp, Peter A. Hogenson, and Wendall D. Emde of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 81 on the TSP Request Card.*

MSC-20850



Small Pits and Scratches on a metal foil indicate that abrasive particles struck the surface during a wind-tunnel test.

Monitoring Temperatures Indirectly in Cooled Combustors

Temperature measurements are taken on the outside walls.

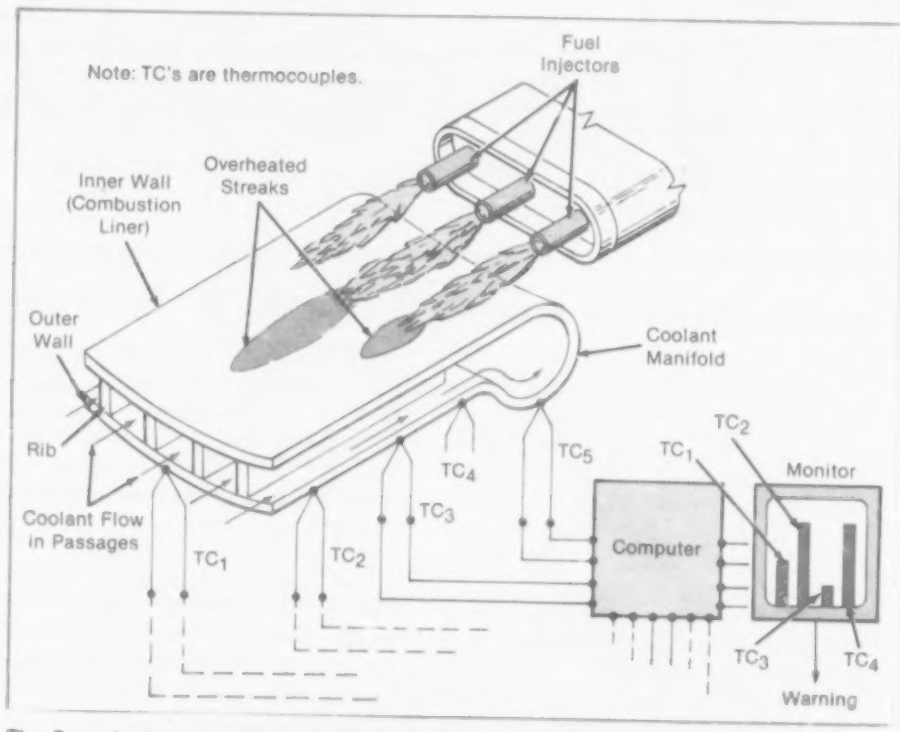
Marshall Space Flight Center, Alabama

A proposed noninvasive monitoring of the temperatures on the inner surface of the combustion liner of a cooled combustor could help increase liner life, thereby increasing combustor reliability and performance. This technique could be used in furnaces, reactors, jet engines, rocket engines, stationary turbines, combustors, and heat exchangers.

Typically, the coolant flows more or less parallel to the long axes of the individual channels (see figure), with very little lateral mixing.

The heating of the combustion liner is typically nonuniform, with overheated streaks (selectively hot and heat-damaged areas) developing lengthwise on the linear surface. These streaks in turn cause increased heating of the coolant along the corresponding channel, selectively reducing the cooling action of the fluid downstream of this location. This in turn causes the longitudinal section of the liner to overheat still further.

The problem is particularly acute when the coolant is a gas, because, as



The **Growth of Internal Overheating Streaks** could be monitored using the output from an array of thermocouples on the outside wall of the combustor. Computer analysis of this output would indicate the temperature pattern on the combustor lining.

its temperature is significantly increased, its density and hence its mass flow rate is significantly decreased. Eventually the streaks may be the sites of fatigue, cracking, splitting, and ultimately the loss of coolant through the wall. If unchecked, such damage could lead to overall failure.

To locate and monitor these developing overheating streaks, an array of wire-type thermocouples would be placed at various points along the length and the circumference of the outside wall of the combustor and insulated to prevent heat loss to the environment. Because this technique is noninvasive, a large number of thermocouples can be used. The outer wall would be heated indirectly by heat transferred from the combustion lining via the cooling fluid; the temperature pattern in the outer wall would correspond to the pattern in the liner, being modified and displaced in a predictable manner by the coolant flow.

The output of the thermocouple array would be passed to a computer, which would use the appropriate heat-transfer theory to infer a temperature profile of the combustor lining. This output could be presented in any format, including a graphical display with colors and could be continuously recorded.

The use of these data would enable timely liner maintenance or overhaul. It could also guide adjustments; for example, by changing the sizes of the coolant orifices or passages or by changing the fuel-injection mixture ratio in the combustion chamber to retard or prevent the growth of heating streaks.

This work was done by W. R. Wagner of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-29061

Measurement of Dynamic Bolt-Stress

Modification of a static technique gives a complete stress cycle history.

Marshall Space Flight Center, Alabama

An ultrasonic method provides a record of the changing stresses in dynamically loaded bolts; for example, those in vibrating machines, ground vehicles, and aircraft. The method makes available the history of stress cycles, from which the fatigue state and remaining bolt life can be inferred.

Unlike the strain gauges bonded with epoxy to bolt shanks, the ultrasonic sensors are not extremely delicate and are not easily damaged when bolts are removed after testing. The ultrasonic method therefore eliminates laborious and time-consuming replacement of damaged strain gauges. Moreover, it gives true stress measurements rather than the torque or strain measurements.

The new method employs a modified static ultrasonic bolt extensometer. The ultrasonic transducer mounted on a bolt is modified so that it transmits and receives ultrasound pulses at much higher repetition rates. The high data sampling rate yields high-frequency dynamic stress measurements.

This work was done by Sarkis Barkhoundarian of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*
MFS-29058

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Determining Chaotic Instabilities in Mechanical Systems

Theoretical developments may enable the suppression of chaotic structural motions.

A report discusses the theory of chaotic instabilities in mechanical systems having many degrees of freedom. Chaotic motions occur in systems characterized by nonlinearities. These include bilinear springs, unilateral constraints, two-bar linkages, systems with multiple equilibrium states (for example, buckling columns or shells), aeroelastic systems, and structures with feedback control devices. A fully developed theory may enable the prediction, avoidance, and suppression of chaotic vibrations in structures, especially those using dynamic feedback stabilization.

In recent years, researchers have become increasingly aware of the difference between classical and chaotic instabilities. In a classical instability, a small perturbation grows exponentially toward an infinite amplitude. In a chaotic instability, random or aperiodic finite motions are apparently generated by a deterministic system without any random input, and the subsequent trajectories are supersensitive to small changes in the initial conditions.

The classical equations of motion of a system with N degrees of freedom are expressed as the parametrical equations of the trajectory of a point in the corresponding N-dimensional space. (This point represents the instantaneous configuration of the system.) The tangent and normals to the trajectory are then calculated. Assuming that the undisturbed trajectory is known, one can also solve, in principle, the equations for the growth of an infinitesimal initial perturbation in the trajectory. If the perturbation begins to grow exponentially, the motion is chaotic.

It must be emphasized that the chaotic nature of a mathematically predicted motion is the result of inadequacies in the mathematical model. All of the functions on which mechanical theory has been based are assumed to be differentiable as many times as necessary for mathematical convenience. However, the assumption of differentiability is not always physically realistic and is not re-

quired by the principles of mechanics nor by the definition of continuity. The behaviors of real systems are not always describable by smooth functions. The prediction of chaotic motion is the mathematical penalty for the unjustifiable assumption of smoothness.

Current efforts are directed toward including nondifferentiable functions in system descriptions so that predicted motions that formerly seemed chaotic become deterministic. The essence of this approach is the search for a noninertial reference frame that oscillates or moves with a nonsmooth transport velocity. The fluctuating components of velocity (for example, turbulence in a fluid) are expressed in the moving reference frame.

The solution of the equations of motion requires the calculation of a feedback function. The Lagrange equations of motion for the fluctuating velocity components are coupled with the feedback differential equations. The solution gives a deterministic description of the motion that formerly seemed chaotic. In the new formulation, the motion is both repeatable and predictable: Small changes in the initial conditions lead to small changes in both the mean and fluctuation velocities.

This work was done by Michail A. Zak of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Chaotic Instability in Mechanical Systems," Circle 15 on the TSP Request Card.*
NPO-16709

Multishaker Modal Testing

Abstracts summarize time- and frequency-domain component-mode synthesis methods for damped systems.

The abstracts of six papers on vibration analysis and a summary of the contributions and recommendations contained in them are presented in a 14-page report on multishaker modal testing. The collection includes four reports published by the Center for Aeronautical Research, a paper accepted for publication in the journal of the American Institute for Aeronautics and Astronautics, and a paper presented at the Fourth International Conference on Applied Numerical Modeling.

The principal contributions and recommendations reported are the following:

1. A component-mode synthesis method for systems with general viscous damping has been developed. The inclusion of residual attachment modes as well as free-vibration modes increases the convergence rate. Further work to improve the efficiency of this method is recommended.
2. Methods of component-mode synthesis in the frequency domain have been explored. It has been shown that digital Fourier transforms can be used to compute the transient response of a coupled structure.
3. A robust, multi-input, multioutput modal-parameter estimation algorithm requiring little user interaction has been developed for identifying frequencies, damping values, and mode shapes of systems with general viscous damping. It applies to general linear, time-invariant systems. It results in reduced system matrices, which might be very useful in such applications as the control of flexible structures. Other applications of the algorithm should be explored, and the algorithm should be compared with other modal-parameter estimation algorithms, such as the Polyreference algorithm.

This work was done by Roy R. Craig, Jr., of the University of Texas for **Marshall Space Flight Center.** *Further information may be found in NASA CR-178507 [N85-33544/NSP], "Multishaker Modal Testing."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 83 on the TSP Request Card.
MFS-27132

Fatigue Criterion for System Design

A report discusses principles of structural-life prediction.

A fundamental principle of good design is to recognize that any structure can fail. The structure should be so designed that its failure does not cause personal injury or secondary damage. Once a structure is designed to fail in a benign manner, it then can be designed for finite life so that the overall size, weight, and cost can be reduced and still meet the reliability requirements of the application.

The design of machine elements is based, for the most part, on yield stresses and fatigue-limiting stresses. In addition to the material properties of components, proper consideration must be given to the effects of notches, surface condition, component size, residual stress, temperature, duty cycle, and such environmental factors as corrosive or chemical exposure. For most machine elements, individuals and organizations usually develop design methods based upon engineering fundamentals found in most machine-design texts and upon factors based upon their corporate experience and test data. As a result, it is not too unusual for different organizations or individuals, starting with the same or similar design requirements, to reach dissimilar conclusions or designs while seemingly applying the same fundamental engineering principals to the problem.

Setting aside the subjective, creative aspects of design, there appears to be nonuniformity of data from which numbers and design factors are selected, as well as differences in the computer codes and boundary conditions used in the design process. To compound these difficulties, the fatigue data used to establish fatigue limits are usually of a limited nature, with the conditions under which the data were obtained not adequately defined or reported. Such items as temperature, humidity, number of specimens, specimen size and volume, heat treatment, hardness, surface finish, and life distribution are not given.

The established fatigue limit for much of the reported data is a mean value. From a statistical viewpoint, the median value is equal to or less than the mean. This can be interpreted as meaning that before a fatigue limit is reached there is a probability that 50 percent of the specimens will have failed; that is, even at the fatigue-limit stress, life is finite. Experienced design engineers have recognized this for years, and they have added safety factors to their design procedures usually based on experience. While these procedures are generally adequate, they can result in overdesigned, oversized, overweight, and overcost structures.

A generalized methodology has been developed for structural life prediction, design, and reliability, based upon a fatigue criterion. The life-prediction methodology is based in part on work of W. Weibull, G. Lundberg, and A. Palmgren. The approach incorporates the computed life of elemental stress volumes of a complex machine element to predict system life. The results of coupon fatigue testing are incorpor-

ated into the analysis, allowing for life prediction and component or structural renewal rates, with reasonable statistical certainty.

This work was done by Erwin V. Zeretsky of **Lewis Research Center**. *Further information may be found in NASA TM-87017 [N85-27226/NSP], "Fatigue Criterion to System Design, Life and Reliability."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14344

Scuffing and Lubrication of Gears and Bearings

A new Reynolds equation is developed for elastohydrodynamic-lubrication analysis.

Scuffing is a problem encountered in gears and rolling-element bearings. In rolling-element bearings, for example, scuffing is found in the acceleration zones of large, heavily loaded bearings. For these circumstances, inertia effects lead to high sliding speeds. Scuffing is related to lubrication-film thickness failures leading to metal-to-metal contact. High surface stresses lead to rolling-bearing fatigue, and high surface temperatures may cause local melting of the surfaces.

Because the surface temperature can be calculated if the kinematic and surface stresses are known, important parameters to control when one is studying scuffing are the film thickness and the surface stresses. These parameters can be calculated by use of elastohydrodynamic lubrication (EHL) analysis.

A new method was developed to study macro- and micro-EHL, without restriction on the load applied to the contact. Macro-EHL refers to the lubricant-film thickness developed in the inlet zone of the EHL conjuction. Micro-EHL may occur below the asperities and is due to the squeeze or sliding-speed effects in the bearing. Macro-EHL is first studied by use of the classical Reynolds equation (linear viscous-fluid model), and the results are accurate for any applied loads. Under severe conditions (large pressure and high sliding speeds), the lubricant behavior can no longer be considered to be linearly viscous; a nonlinear viscosity model is needed.

A new Reynolds equation takes into account the nonlinear viscous behavior of the fluid. The Reynolds equation and the elasticity equations are solved simultaneously by a system approach and the Newton-Raphson technique. The film thickness, pressure, and shear stress can be obtained without load restrictions. This new method therefore is a very powerful tool that can be used to study scuffing. Using this new approach, the researchers have analyzed stress concentrations near both a bump and a groove in a bearing surface.

This work was done by B. J. Hamrock of **Lewis Research Center** *and L. G. Houpert of the National Research Council. Further information may be found in NASA TM-87097 [N85-34408/NSP], "Elastohydrodynamic Lubrication Calculations Used as a Tool to Study Scuffing."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14364.

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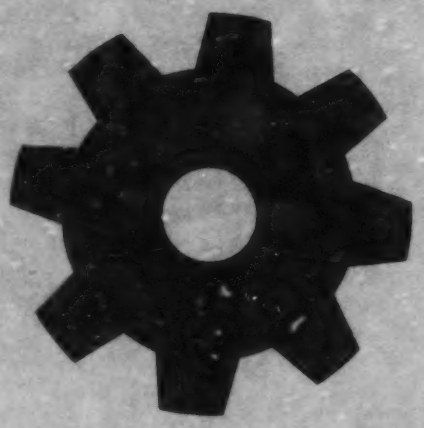
Circle Reader Action No. 374

Machinery



Hardware, Techniques, and Processes

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93 Centrally-Rupturing Squib-Closure Disks
94 Retractable Sun Shade
95 Direction-Sensitive Latch
96 Mobile Remote Manipulator
97 Lightweight Motorized Valve
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100 New Alloy for Glass-to-Metal Seals
100 Torque-Summing Brushless Motor
101 Cleaning High-Voltage Equipment With Corncob Grit
102 Hydraulic-Leak Detector for Hidden Joints
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Liquid Scavenger for Separator/Pump

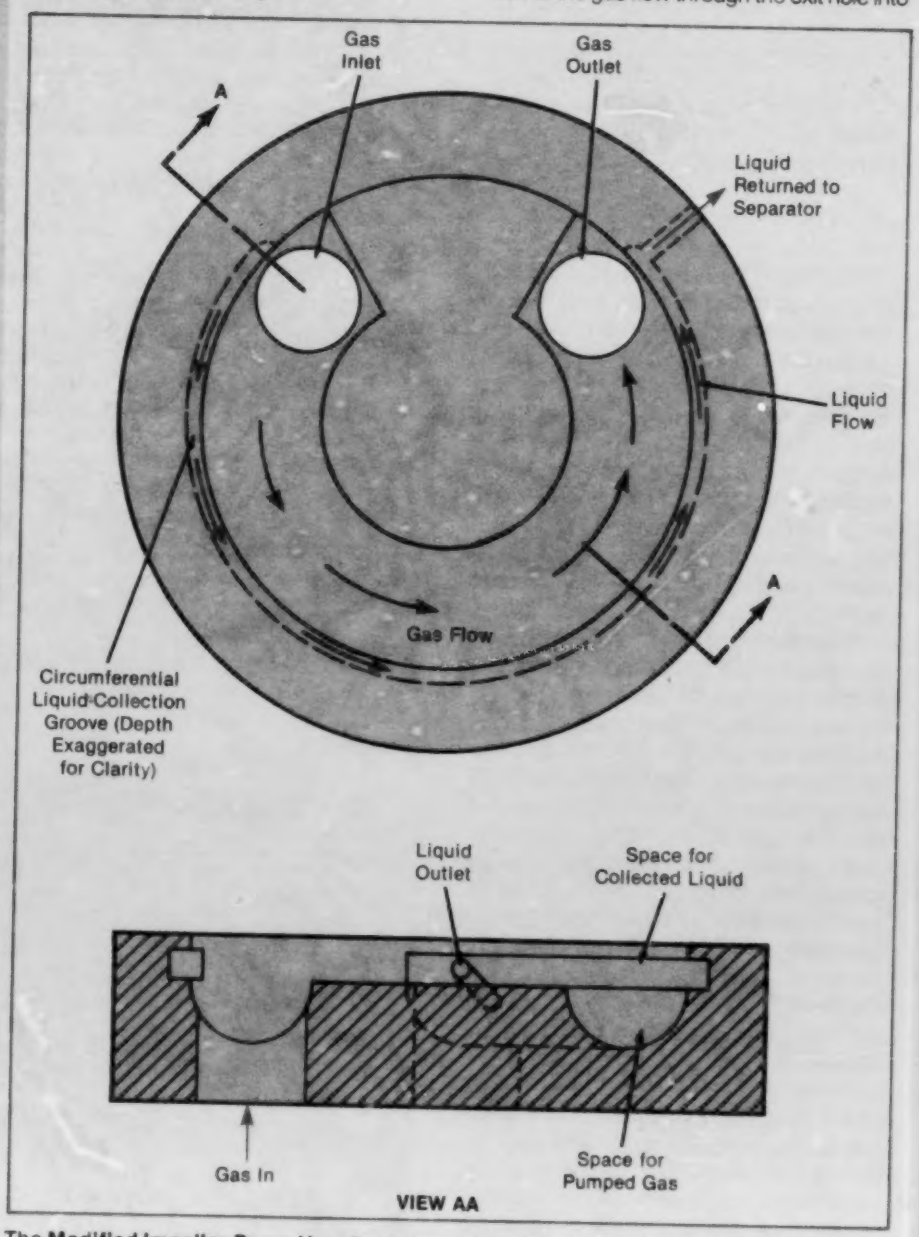
Aerodynamic drag impels condensate along a groove to an exit hole.

Lyndon B. Johnson Space Center, Houston, Texas

A pump for hydrogen has been modified to remove moisture that condenses in the impeller stage. The moisture is returned to the centrifugal separator stage for removal from the system.

Normally, the separator removes water droplets from an incoming mixture of hydrogen gas, water droplets, and water vapor. In the unmodified pump, however, additional condensation sometimes occurs in the impeller stage.

The moisture-removal problem is solved by adding a shallow circumferential groove and a small exit hole to the impeller chamber (see figure). As the impeller wheel rotates, the condensate is forced toward the outer wall of the chamber, where it collects in the groove. Aerodynamic drag impels the water around the groove toward an exit hole located at the high-pressure region of the chamber. The condensate and a small portion of the gas flow through the exit hole into



The **Modified Impeller-Pump Housing** has a circumferential groove that leads to an exit hole near the high-pressure outlet. As the impeller disk (not shown) rotates, it flings water droplets that have condensed in the pump toward the groove. Aerodynamic drag drives the water around the groove to the exit hole.

a tube that leads back to the separator stage inlet, which is the point of lowest pressure in the system.

Depending on the impeller tip speed and pressure, droplets as small as 10 μm may be removed. Since the droplets are formed by condensation, the final drop size depends on the pump compression ratio. The higher the ratio, the larger the droplets, and the more water will be removed.

The moisture-removal modification may reduce the effectiveness of pumping, especially with such low-molecular-weight gases as hydrogen. To minimize the loss of pumping pressure, the groove must be as shallow as possible and the exit hole as small as possible consistent with adequate moisture removal. Alternatively, moisture removal could be achieved by using an auxiliary dryer downstream. In deciding which method to use in a given application, the pressure losses for the two methods should be compared.

This work was done by Paul F. Berg of United Technologies Corp. for **Johnson Space Center.** *No further documentation is available.* *MSC-20632*

Centrally-Rupturing Squib-Closure Disks

The rupture-disk design makes squib action more predictable.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed squib rupture disk would insure that the squib explosion is directed toward the center of a combustion chamber. This can obviate the use of oversize squib units that can cause undesirably large impluses.

Conventional squibs are fabricated with round, stainless-steel rupture disks, attached to the squib bodies by electron-beam welding (see Figure 1). Each disk has uniform thickness, typically 5 mils (0.13 mm). Because the weakest section in the disk is somewhere in the weld, pressure buildup in the squib invariably causes the disk to fail somewhere along the circumferential weld seam. Consequently, the combustion material is propelled toward the side and hence along the combustion-chamber wall.

It is not possible to predict how large the initial opening will be and what amount of the combustion material will be thrown against the wall of the combustion chamber downstream of the squib. (The maximum pressure developed in the combustion chamber varies randomly from test to test.) In view of this unpredictability, it has become the practice to use oversized squib units.

In the new design (see Figure 2), the center of the rupture disk contains a cruciform indentation in which the thickness is reduced to about 0.5 mil (0.013 mm). This reduces the strength of the center of the rupture disk in the same manner as that of the pull tabs on beverage cans; therefore, the disk will fail predictably in the center.

With this design, the expulsion of combustion material is expected to be uniform and predictable, making it unnecessary to use oversized squib units. Moreover, the flow from the ruptured squib will be directed advantageously toward the center of the combustion chamber.

This work was done by Robert Richter of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 16 on the TSP Request Card.* *NPO-16707*

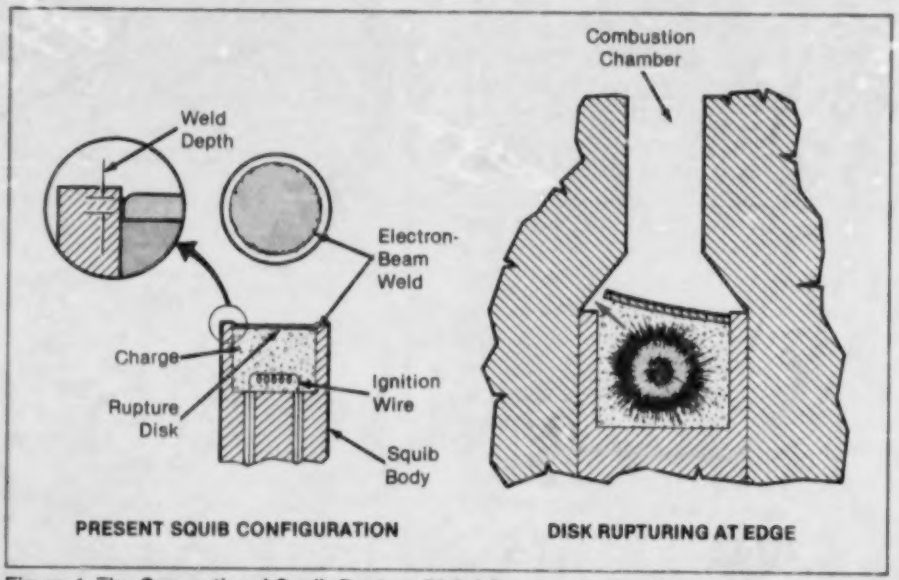


Figure 1. The **Conventional Squib Rupture Disk** fails where it is welded to the squib body, causing an unpredictable flow of combustion products toward the walls of the combustion chamber.

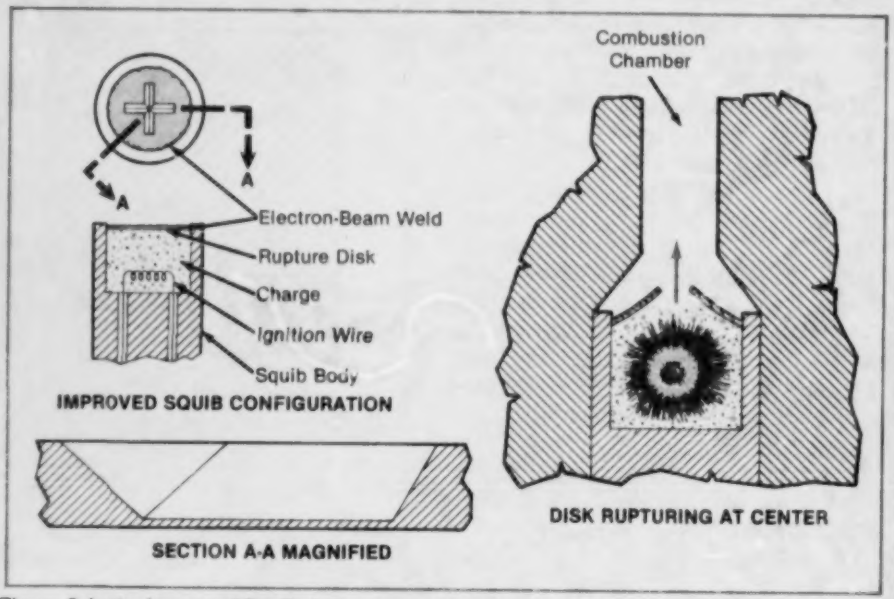


Figure 2. In the **Improved Squib,** failure occurs predictably at the center of the rupture disk, causing a predictable flow of combustion products toward the center of the combustion chamber.

Retractable Sun Shade

A mechanism unrolls a canopy and rerolls it when shade is no longer needed.

Lyndon B. Johnson Space Center, Houston, Texas

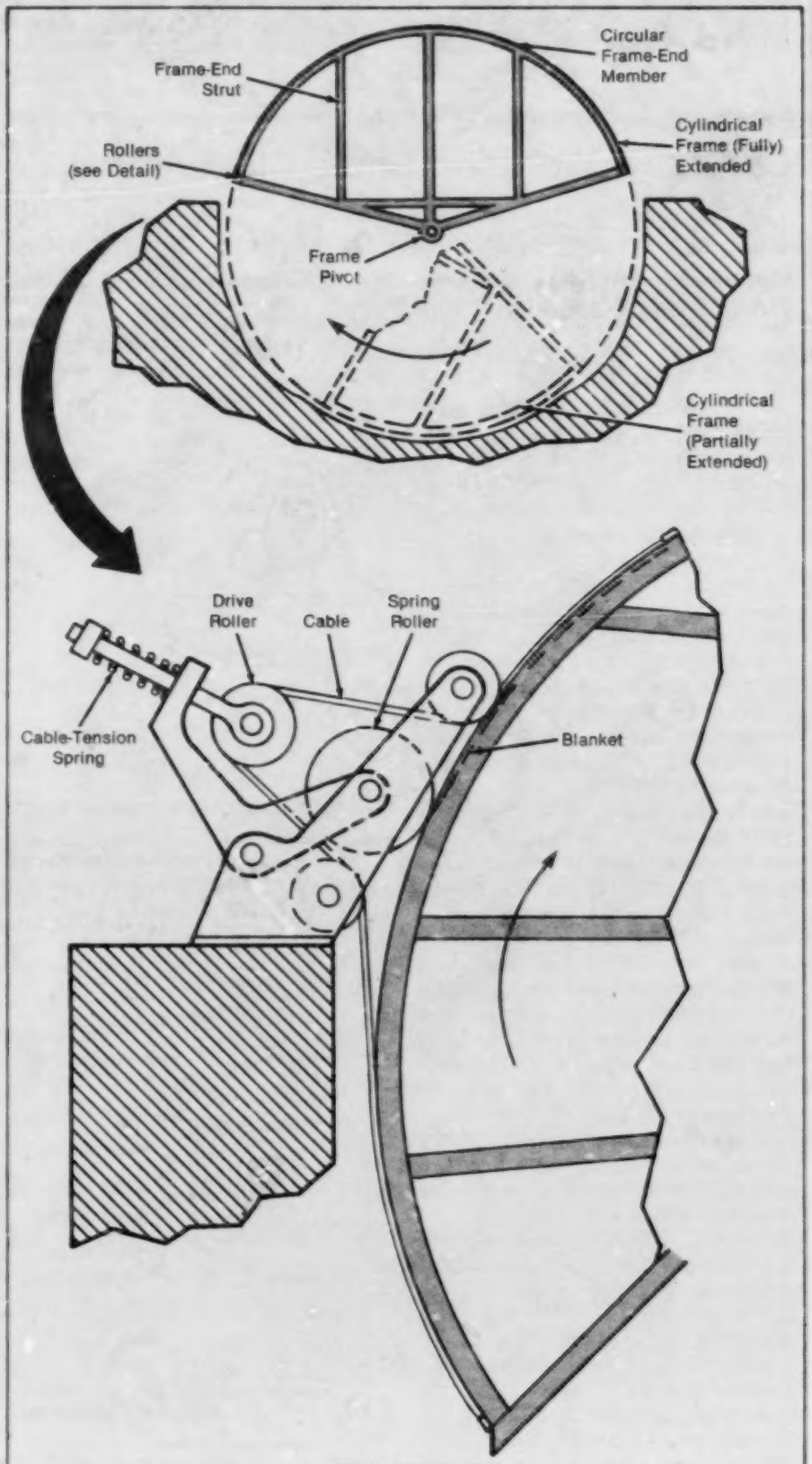
A blanket can be readily unfurled by a mechanism to protect the space it encloses from the Sun. The blanket forms an arched canopy over the space and allows full access to it from below. When shading is not needed, the retracted mechanism stores the blanket compactly. The mechanism was developed for protecting sensitive Space Shuttle payloads from direct sunlight while the cargo-bay doors are open. It can be adapted to the shading of greenhouses, swimming pools, and boats.

To unfurl the blanket, rollers drive cables at the end of a cylindrical frame (see figure). As the frame rotates to the right, it draws the blanket from a spring roller in the manner of a common window shade. The driving cables hold the blanket against the circular members at the ends of the frame. Thus, as the blanket unfurls it assumes the cylindrical shape of the frame. When the roller motion is reversed, the cables rotate the cylindrical frame back to its storage position. At the same time, the blanket is drawn by its return spring back into the spring roller.

The drive roller can be powered manually or by an electric motor. It can be stopped at any point, if desired, to provide partial shade instead of full shade. (In the nearly zero gravity of space, the unfurled blanket does not sag on the frame; on Earth, however, additional radial support may be needed.)

This work was done by Arthur Frank, Silvio F. DeRespinis, and John Mockovciak, Jr., of Grumman Aerospace Corp. for **Johnson Space Center.** *For further information, Circle 29 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20162.



A Window-Shade Type Spring Roller contains a blanket, which is taken up by a rotating cylindrical frame and held by the frame over the area to be shaded. The blanket is made of a tough, opaque polyimide material.

Direction-Sensitive Latch

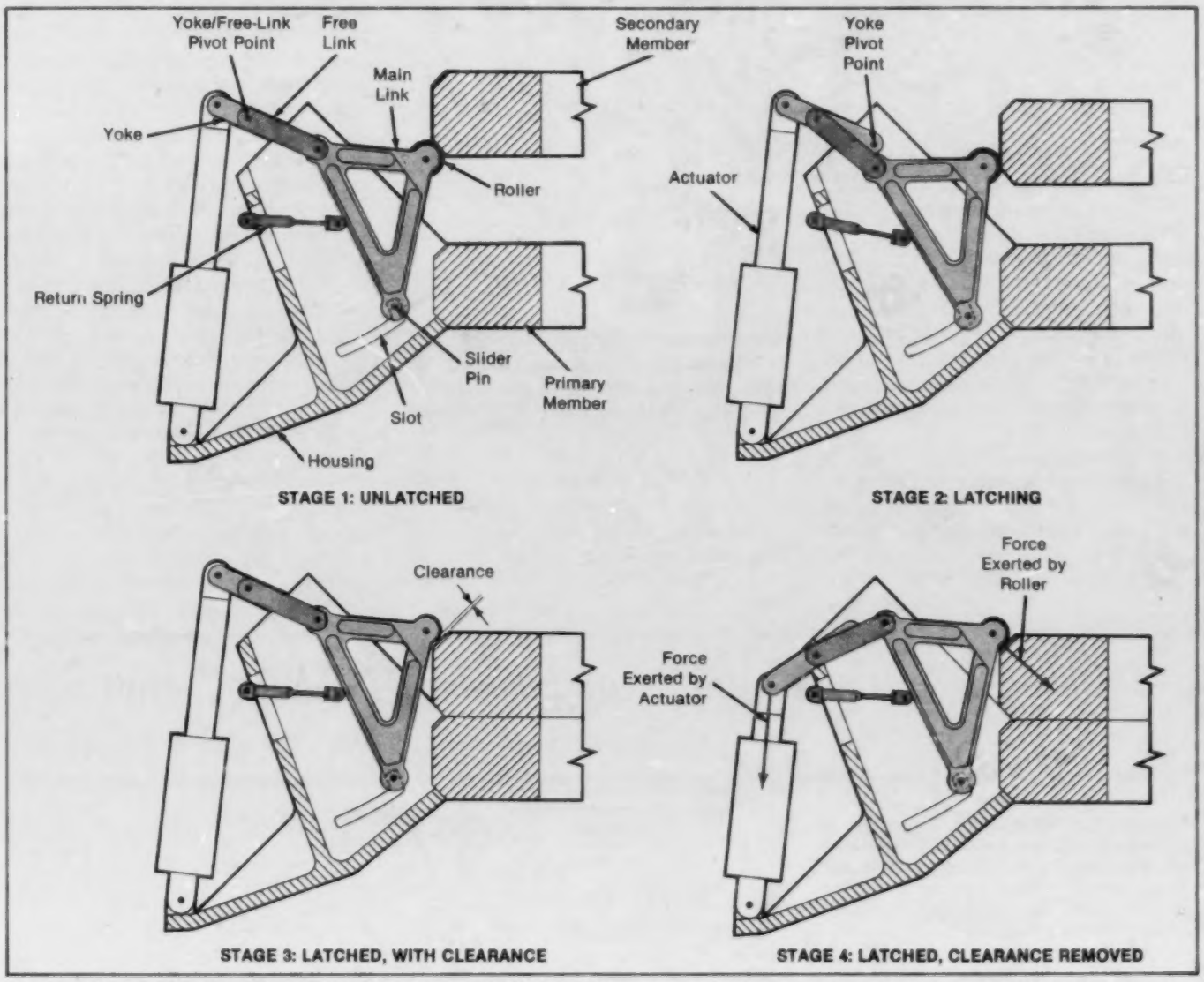
A mechanism eliminates clearance and applies a positive load to a latched member.

Lyndon B. Johnson Space Center, Houston, Texas

A latching mechanism eliminates clearance between itself and a latched member. It is simpler and lighter than previous direction-sensitive latches (also called "vector-sensitive latches"). Like the previous latches, it responds to the direction of forces in determining whether members should be accepted, held in position, or released. However, unlike the previous latches, it eliminates the need for an auxiliary latch to press the mechanism against the latched member for retention. The new mechanism is well suited to operation by automatic control or by a remotely controlled manipulator.

A roller at an apex of the triangular main link of the mechanism contacts a beveled edge on the member to be latched (see figure). With no force applied, the roller and the member remain in this relationship. However, a force applied to the roller in a direction approximately toward the primary member overcomes the frictional force on the latch slider pin, which then slides in a slot in the latch housing. The latch collapses, allowing the secondary member to pass the roller and contact the primary member. The roller then returns to its original position, where it latches the secondary member in place.

There is now a small clearance between the roller and the latched secondary member. The clearance is necesary to allow for dimensional variations in the parts due to manufacturing tolerances and thermal expansion or contraction. However, the clearance must be eliminated after latching so that the latched members are held tightly together. Accordingly, the actuator is designed to exert a force on the yoke, rotating the yoke counterclockwise about the yoke pivot point. This pushes the roller against the secondary member with a force perpendicular to the beveled edge. The clearance is thus taken up, and a retaining force is applied to the latched secondary member.



The **Stages of the Latching Process** begin with the application of a downward force to the secondary member, causing it to displace the roller. After the secondary member has passed the roller and joined the primary member, the actuator removes the clearance between the roller and the secondary member.

The secondary member can be unlatched in either of two ways. The actuator can be used to move the yoke and free link to the open-latch position, or the secondary member can be tilted. Beyond a certain tilt angle, the forces are redirected so that the roller no longer retains the secondary member.

Several variations of the latch mechanism are possible. For example, the latch housing can be a separate part, or it can be an integral part of one of the members. The slot that controls the movement of the main link can be machined in the housing or in the main link. The yoke can be moved by a hydraulic actuator or by a spring, gear motor, or other means. The yoke can be replaced by any other part that rotates about the yoke pivot point and causes movement of the free-link connecting point for clearance removal.

This work was done by William R. Acres of **Johnson Space Center.** *For further information, Circle 73 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20910.

Mobile Remote Manipulator

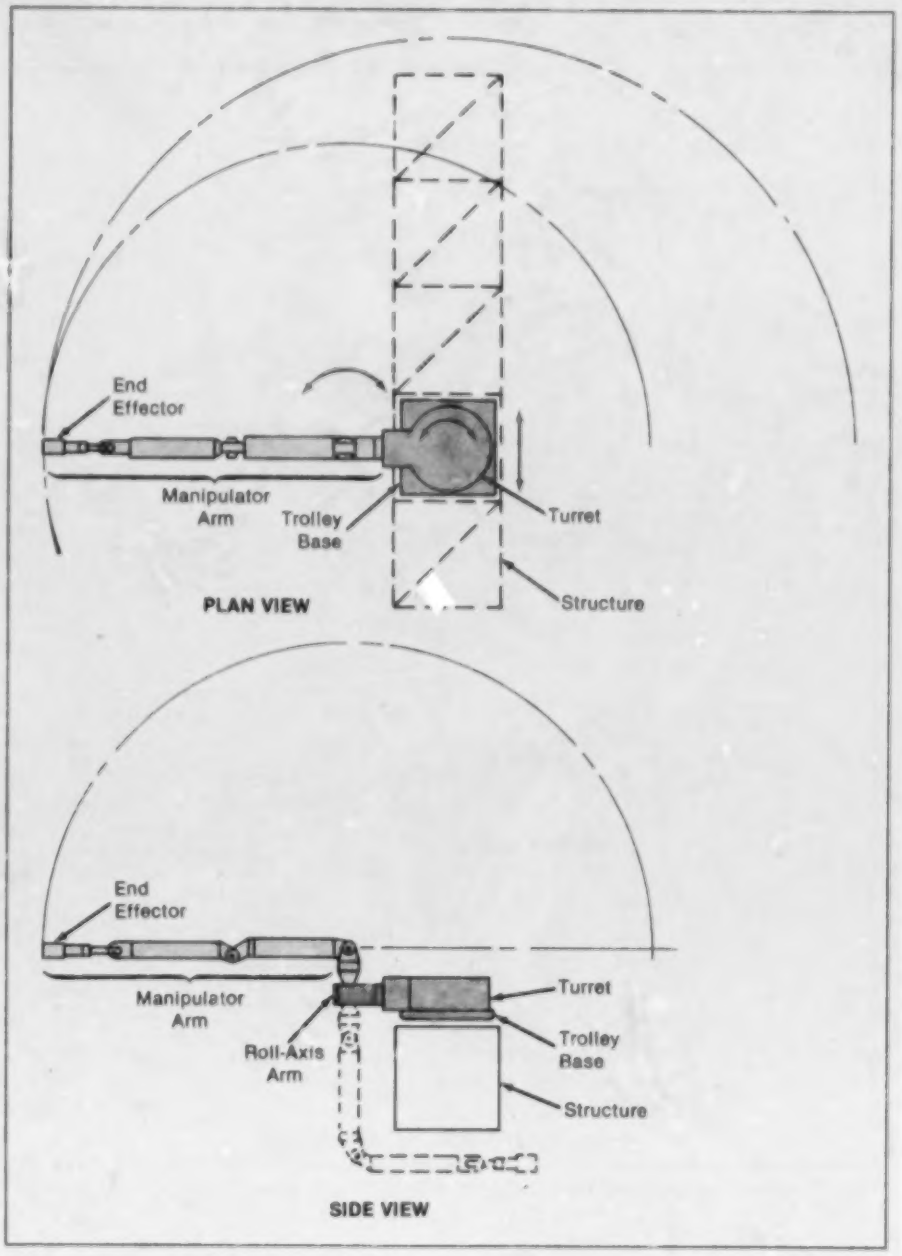
A turret, roll arm, and trolley enhance manipulator dexterity.

Lyndon B. Johnson Space Center, Houston, Texas

A mobile remote manipulator has seven degrees of freedom. Designed for handling, inspecting, and maintaining the modules of a space station, the manipulator can extend the end effector to points on, around, and under the space-station structure. Manipulators having such capabilities may be useful on Earth; for example, as robots in manufacturing, for the erection of large structures, or for performing complicated tasks in hazardous locations.

The manipulator moves on a vehicle that provides one-degree-of-freedom movement (translation) along the structure and two degrees of freedom by a rotating turret top (yaw) and an arm (roll). A jointed manipulator arm attached to the roll-axis arm provides additional degrees of freedom.

This work was done by Stanis Coryell and Roy E. Olsen of Grumman Aerospace Corp. for **Johnson Space Center.** *For further information, Circle 72 on the TSP Request Card.*
MSC-21051



The **Remote Manipulator Moves on a Trolley** base along a structure. The roll-axis arm positions the manipulator arm so that it can extend the end effector under the structure. The yaw-axis rotation gives added reach to the arm above the structure.

Lightweight Motorized Valve

A redesigned actuator assembly weighs 50 percent less than before.

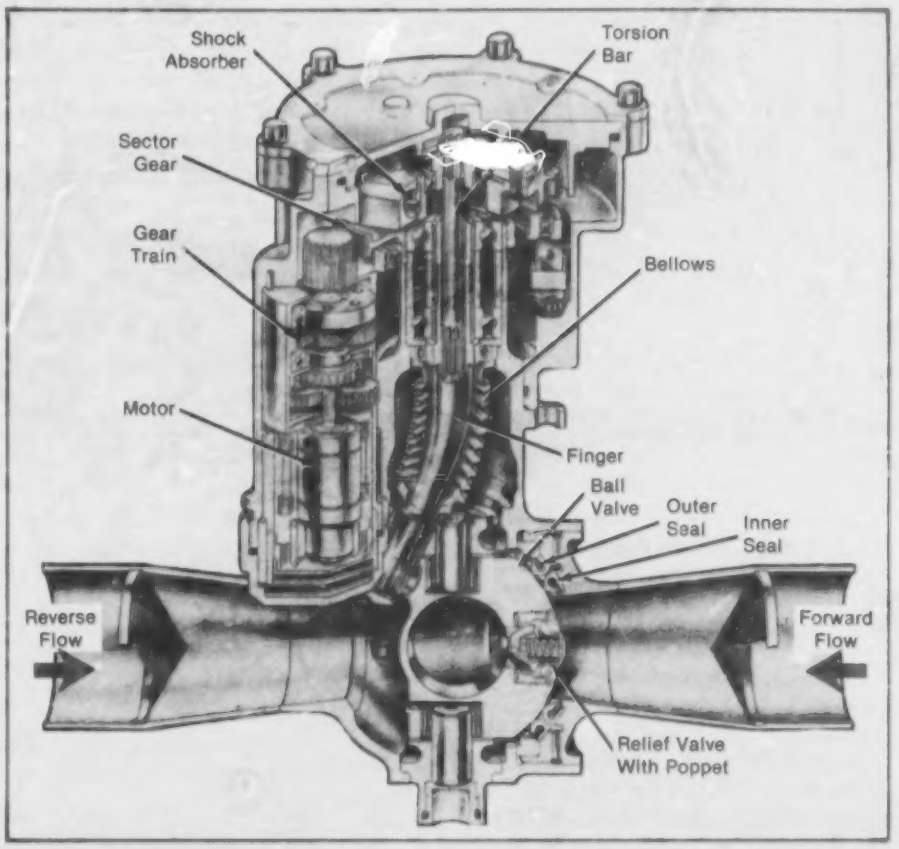
Lyndon B. Johnson Space Center, Houston, Texas

An isolator valve is operated by an ac motor instead of the usual dc solenoid. The valve weighs only 3 lb (1.4 kg) — half the weight of a dc-operated valve. In addition, the new valve functions with either two-phase or three-phase power.

The new valve seals against fluid movement in both the forward and reverse directions. Developed for isolating fluids in the propellant tanks, manifolds, and interconnecting lines of the Space Shuttle reaction control and orbital maneuvering subsystems, the valve is well suited to applications in which leakage must be kept to a minimum at high pressure differences — in petroleum and chemical processing, for example.

The ac motor, gear train, sector gear, and torsion bar operate a finger that opens and closes a ball valve (see figure). The finger extends through a bellows to the ball. The bellows are filled with a material that damps pressure differences across it. The torsion bar ensures that the ball is held open or closed against its stops with a spring force greater than the potential reverse forces of the fluid and, therefore, is not moved substantially by the fluid. Shock absorbers stop the gear train at the designated limits of travel so that the impacts on gears and bearings remain within safe limits. The shock absorbers also prevent the sector gear from bouncing excessively when it reaches its limits of travel.

The ball valve rotates about an axis slightly displaced from its geometrical center. It therefore clears the seals rapidly, causing less seal wear than it would if rotated about the center. The inner seal prevents forward flow, and the outer seal prevents reverse flow. Each seal contains a flat spiral spring that provides a sealing pressure of 200 lb/in.^{2} (1.4 MN/m^2).



A **Motor Drives a Gear Train**, thereby turning a finger that opens or closes a ball valve. The motor-and-gear actuator assembly can be removed and replaced without removing the ball valve or otherwise invading the unit.

The valve contains a relief valve that automatically releases heat-induced pressure from the outlet to the inlet port. This is a spring-loaded poppet containing a soft spring-loaded seal.

This work was done by Rudy Gonzalez of Rockwell International Corp. and J. M. Vandewalle of Parker-Hannifin Corp. for **Johnson Space Center.** *For further information, Circle 3 on the TSP Request Card.*
MSC-20848

Heat Pipes Reduce Engine-Exhaust Emissions

Increased fuel vaporization raises engine efficiency.

Lewis Research Center, Cleveland, Ohio

Heat-pipe technology has increased the efficiency of heat transfer beyond that obtained by metallic conduction. Heat pipes have been used in a variety of ways to move large quantities of heat at high transfer rates. NASA research has examined heat-pipe application in turbine-engine exhaust systems. New techniques have been developed to address three problem areas that generate exhaust emissions in existing gas-turbine engines. These problems are low combustion efficiency at idle (caused by poor fuel vaporization), high NO_x emissions (caused by high-flame-temperature combustion at takeoff condition), and minimal primary-zone combustor life in rich-burn combustion (in ground power applications).

Heat-pipe technology was applied to each of these problem areas with the following results: The low efficiency at idle

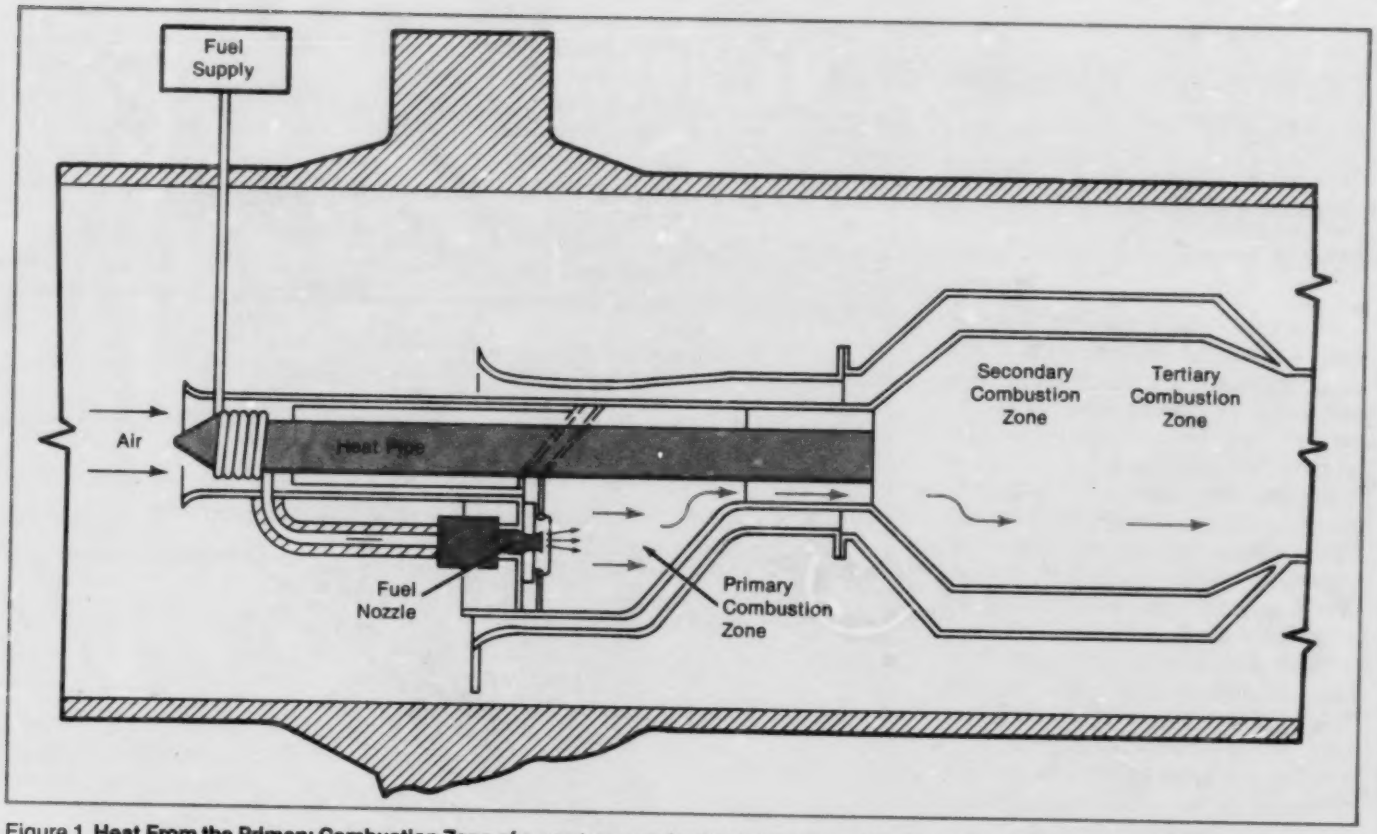


Figure 1. **Heat From the Primary Combustion Zone** of a can-type combustor is transferred by a heat pipe to the fuel and combustion air to increase fuel vaporization.

power was addressed by using heat pipes to warm the combustor inlet air and fuel, thus increasing fuel vaporization. The increased fuel vaporization and resulting combustion increased engine efficiency, thus reducing exhaust emissions of unburned hydrocarbons and carbon monoxide.

Figure 1 shows this technique being applied to the primary zone of a can-type combustor. Note that heat pipe heats only the fuel and primary-zone combustion air. Unheated air is available for cooling the primary-zone walls and the rest of the combustor can. Note also that most primary-zone heat removal occurs at the rear or high-temperature region. This is the same region where NO_x formation is most prevalent at the takeoff-power condition. Therefore NO_x at takeoff is reduced by heat removal in this area.

Figure 2 shows the use of heat pipes to increase liner durability in a fuel-rich primary-zone combustion environment, as is found in the combustion of nitrogenous fuels for the control of NO_x emissions. In this application, heat pipes are used to form the walls of the combustor. The heat pipes in this application have the additional benefit of providing increased fuel vaporization as the fuel again is used as a heat sink. The combustion of No. 4 and No. 6 heating oils can benefit from this increased fuel vaporization.

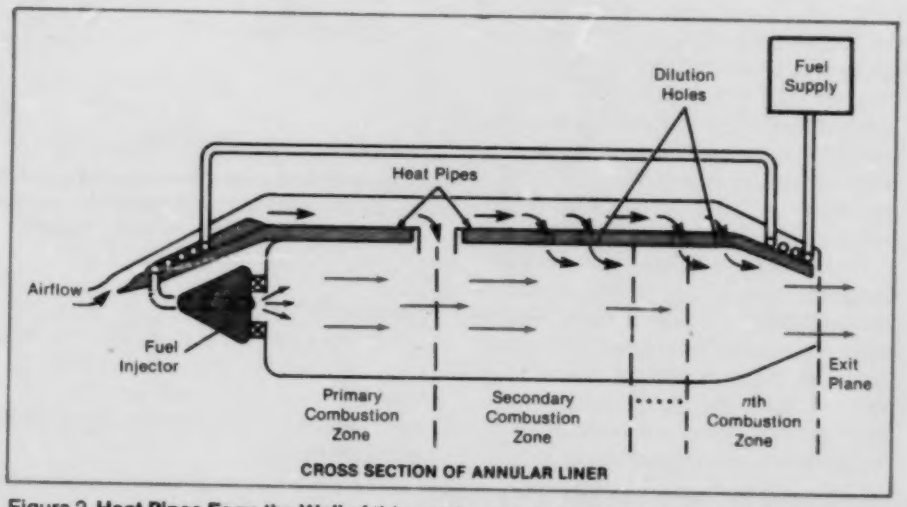


Figure 2. **Heat Pipes Form the Wall** of this combustor. As in Figure 1, the heat pipes transfer some of the combustion heat to fuel to increase its vaporization.

From this work it is apparent that heat-pipe technology can result in both improved engine operation and reduction in fuel consumption. Raw-material conservation through the reduced dependence on strategic materials will also benefit from this type of heat-pipe technology. Future applications will result in improved engine performance and a cleaner environment.

This work was done by Donald F. Schultz of **Lewis Research Center.** *No further documentation is available.*

This invention has been patented by NASA [U.S. Patent No. 4,429,537]. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center, [see page 29]. Refer to LEW-12590.

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New Alloy for Glass-to-Metal Seals

The coefficient of thermal expansion approximates that of glass more closely.

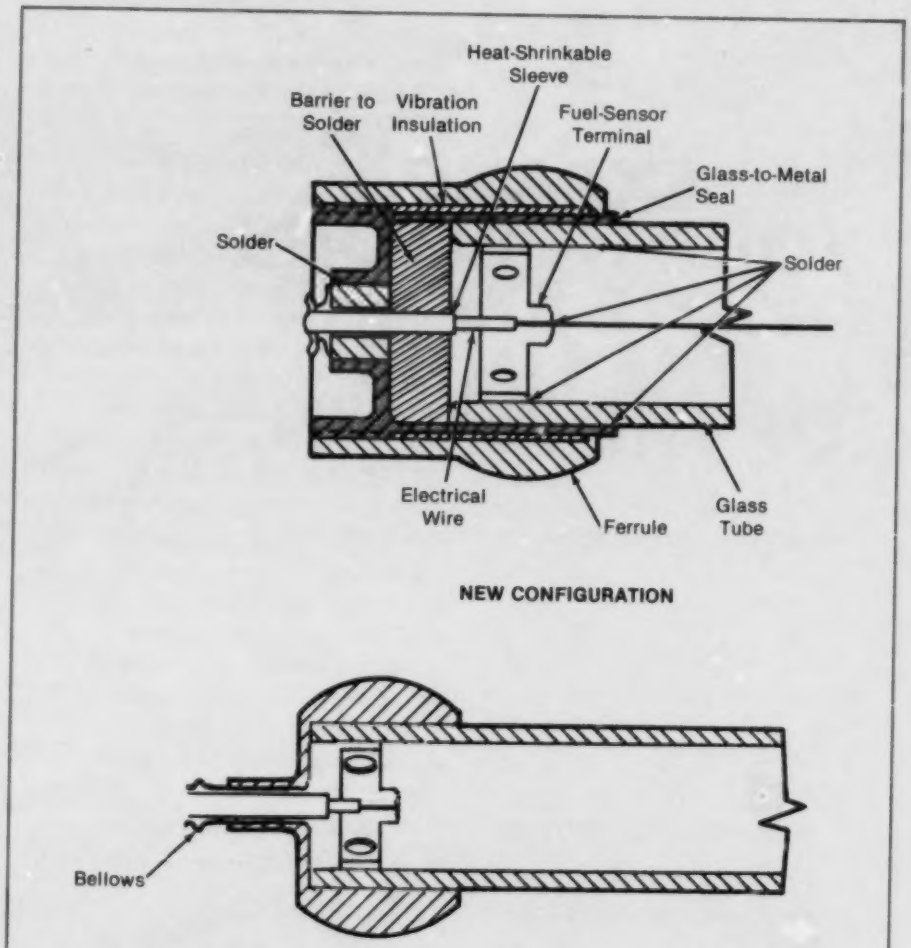
Lyndon B. Johnson Space Center, Houston, Texas

A new alloy has a coefficient of thermal expansion of only $1.9 \times 10^{-6}(°F)^{-1}$ [$3.4 \times 10^{-6}(°C)^{-1}$]. Because the coefficient is close to that of KG-33 (or equivalent) glass, the alloy can be used in glass-to-metal seals without introducing excessive residual stresses. In addition, the alloy has potential for other applications in which low thermal expansion is important; for example, mechanical measuring devices and precise sliding parts that must function over wide temperature ranges.

The alloy is composed of about 60 percent iron, 40 percent nickel, and traces of six other elements. It was developed as a replacement for Kovar (or equivalent) Fe/Ni/Co alloy in a ferrule-and-tube assembly (see figure). The new alloy has about the same strength, solderability, and compatibility with fuel as does Kovar (or equivalent).

Previously, the ferrule was bonded to a glass preform by soldering and heating the glass until it flowed plastically. After cooling, the assembly had a high residual stress because of the difference in thermal expansion between the metal and the glass. Many assemblies failed because of broken glass during manufacturing, testing, shipping, and even storage.

Changing to the new alloy reduced the residual stress in the glass from 4,500 lb/ in.^{2} (31 MN/m^2) to 1,300 lb/in.^{2} (9 MN/m^2). The new value is well below the allowable maximum of 2,000 lb/in.^{2} (14 MN/m^2). The new alloy forms a hermetic seal with glass at a much lower temperature than does Kovar. Changes in the shapes of the parts reduced the glass stress even further.



The **Low-Expansion Alloy** is used for the ferrule of a ferrule-to-tube joint in a fuel sensor.

This work was done by Adolph J. Schmuck of McDonnell Douglas Corp. for **Johnson Space Center**. *No further documentation is available.*
MSC-21023

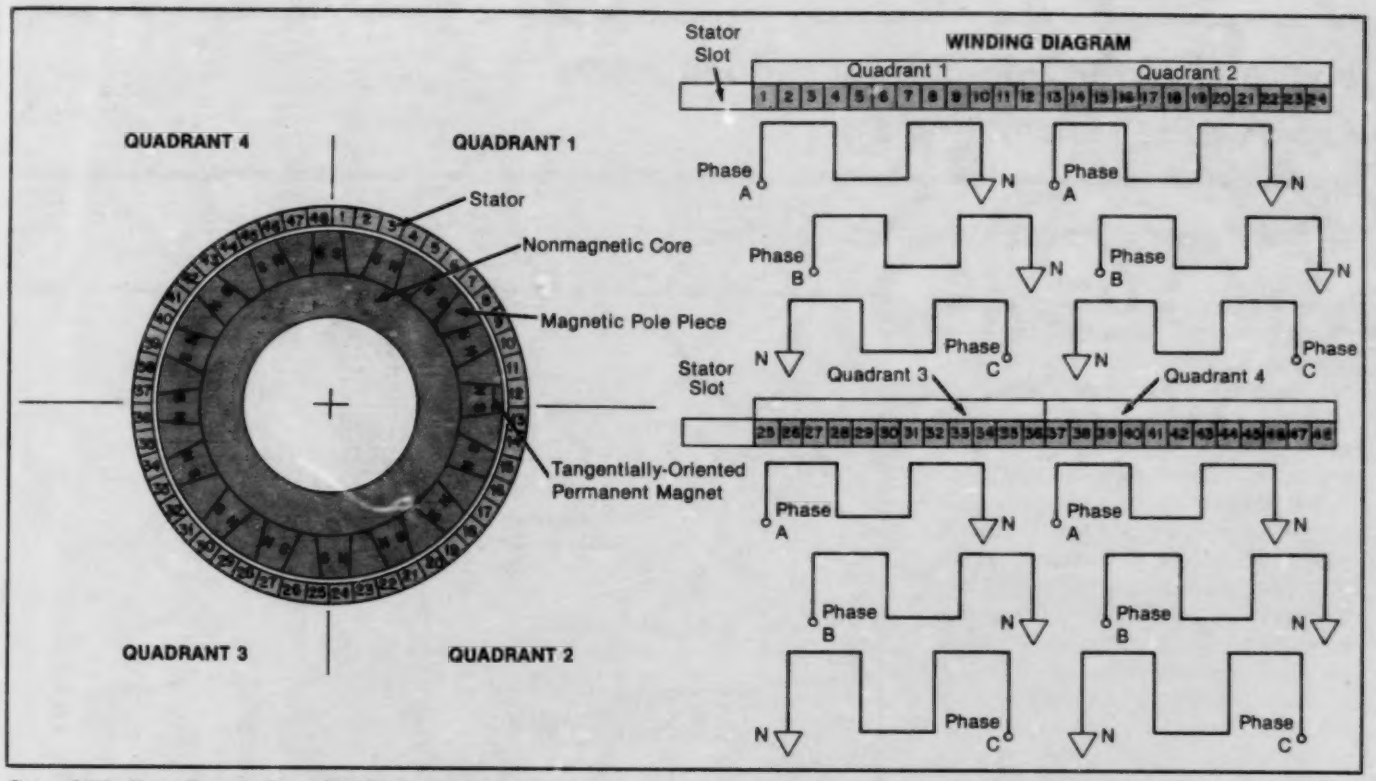
Torque-Summing Brushless Motor

Torque channels function cooperatively but are electrically independent for reliability.

Lyndon B. Johnson Space Center, Houston, Texas

A brushless, electronically-commutated dc motor sums the electromagnetic torques on four channels and applies them to a single shaft. The motor can operate with any combination of channels and can continue to function if one or more of the channels should fail electrically. The motor employs a single stator and rotor and so is mechanically simple; however, each of the channels is electrically isolated from the other so that the failure of one does not adversely affect the others.

The motor consists of a samarium/cobalt permanent-magnet rotor and a stator



Sets of Windings Occupy Separate Quadrants in a four-channel motor. No two windings share a common slot in the stator. Thus if one winding burns out, it does not harm other windings.

with four sets of windings, each in a separate quadrant electrically isolated from the others (see figure). Each set of windings is wired for three phases. Electrical isolation is achieved by use of consequent-pole, full-pitch windings, in which the number of stator slots is an integral multiple of the total number of poles times the number of phases per quadrant. The total number of poles is four times the number of poles per quadrant. A 16-pole, 48-slot motor was designed, built, and tested to demonstrate the concept.

The four-channel motor offers important advantages over other ways of summing torques on a shaft. Four motors on a common shaft, for example, would be costly, large, and heavy and might be subject to critical-speed problems. A single motor with four parallel windings would not have critical-speed problems and would be lighter, but would not isolate the channels electrically, since the windings would be in the same stator slots.

This work was done by Jayant G. Vaidya of Sundstrand Advanced Technology Group for **Johnson Space Center.** *For further information, Circle 55 on the TSP Request Card.* *MSC-20986*

Cleaning High-Voltage Equipment With Corncob Grit

The high electrical resistance of the particles makes a power shutdown unnecessary.

Lyndon B. Johnson Space Center, Houston, Texas

A new, relatively inexpensive method of cleaning high-voltage electrical equipment makes use of a plentiful agricultural product — corncob grit. The method removes dirt and debris from transformers, circuit breakers, and similar equipment. The method is suitable for utilities, large utility customers, and electrical-maintenance services.

With conventional methods, it is necessary to turn off the power in a substation so that workers can clean high-voltage devices by hand. Meanwhile, the buildings and facilities connected to the substation are without power. The use of the new method, in contrast, makes it possible to proceed with the equipment energized.

The procedure is similar to sandblasting. The corncob grit is fed from a hopper into a 1-in. (2.54-cm) airhose, where air from a compressor forces it through a tapered nozzle onto the surfaces to be cleaned. The abrasive action of the grit quickly removes caked dirt. The high electrical resistance of the grit prevents high-voltage arcing and tracking; a compressor capacity of 600 ft^3/min (0.28 m^3/s) is adequate.

The cost is moderate — about 10 cents per kilovolt-ampere of capacity (1979 prices). For example, it has been estimated that the costs of cleaning a 10^4-kVA power substation are the following:

- $100 for 400 lb (180 kg) of corncob grit;
- $110 for rental of a 600-$ft^3$/min (0.28-$m^3$/s) air compressor; and
- $800 for 32 manhours of labor.

This work was done by C. E. Caveness of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20180

Hydraulic-Leak Detector for Hidden Joints

Slow leakage of fluid is made obvious.

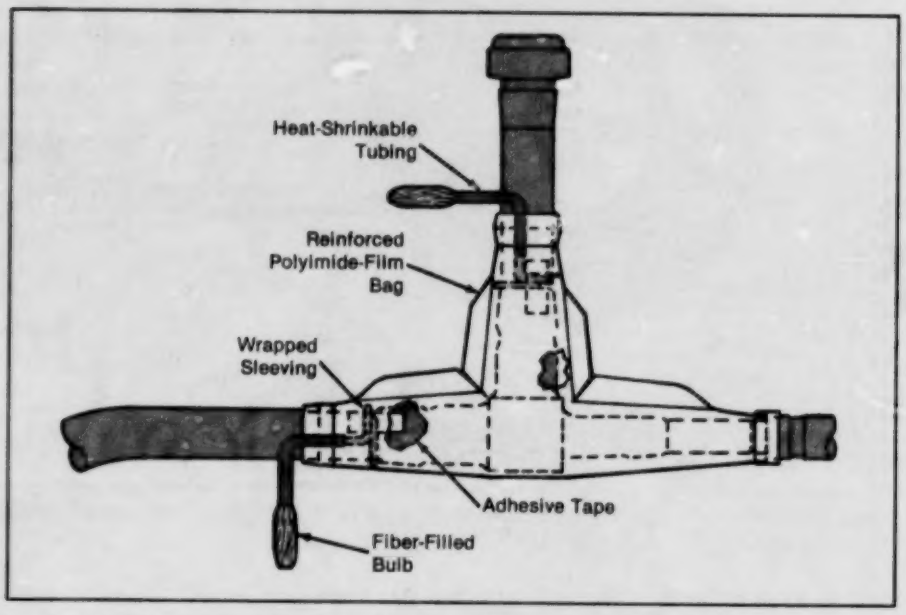
Lyndon B. Johnson Space Center, Houston, Texas

An indicator reveals leaks in hidden fittings on hydraulic lines. It allows fast inspection of joints without disassembly. It can be used in aerospace, petroleum, chemical, nuclear, and other industries where removing covers for inspection is impossible, difficult, or time-consuming.

The indicator consists essentially of a wick wrapped at one end around the joint to be monitored. The wick absorbs hydraulic fluid leaking from the joint and transmits it to the opposite end, which is located outside a cover plate and is therefore visible to an inspector. Leakage is thus manifested as a discoloration of the outside end of the wick.

The wick is Kevlar (or equivalent) aramid sleeving, a material that absorbs and propagates hydraulic fluids. At the end of the wick is a bulb filled with fibrous insulation to make the fluid more evident (see figure). The portion of the wick leading to the bulb is sheathed in heat-shrinkable tubing. The sheathed part is shaped by holding it in position while heat is applied; it retains its new shape when it has cooled. The unsheathed portion of the wick is taped to the joint to be monitored.

The indicator had been tested to demonstrate its ability to serve as a leak detector and to survive random vibration. It is inexpensive, easily adapted to a variety of fitting shapes, light in weight, and easy to install. On the Space Shuttle, where about 2,000 hydraulic joints must be checked for leakage, it has greatly speeded postflight inspection.



Two Leakage Indicators were wrapped on a fitting for tests in which oil was injected into a polyimide bag surrounding the fitting.

This work was done by George E. Anderson and Shu Loo of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 74 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20783.

Measuring Continuous-Path Accuracies of Robots

Sensors yield data on deviation from a predetermined path and speed.

Marshall Space Flight Center, Alabama

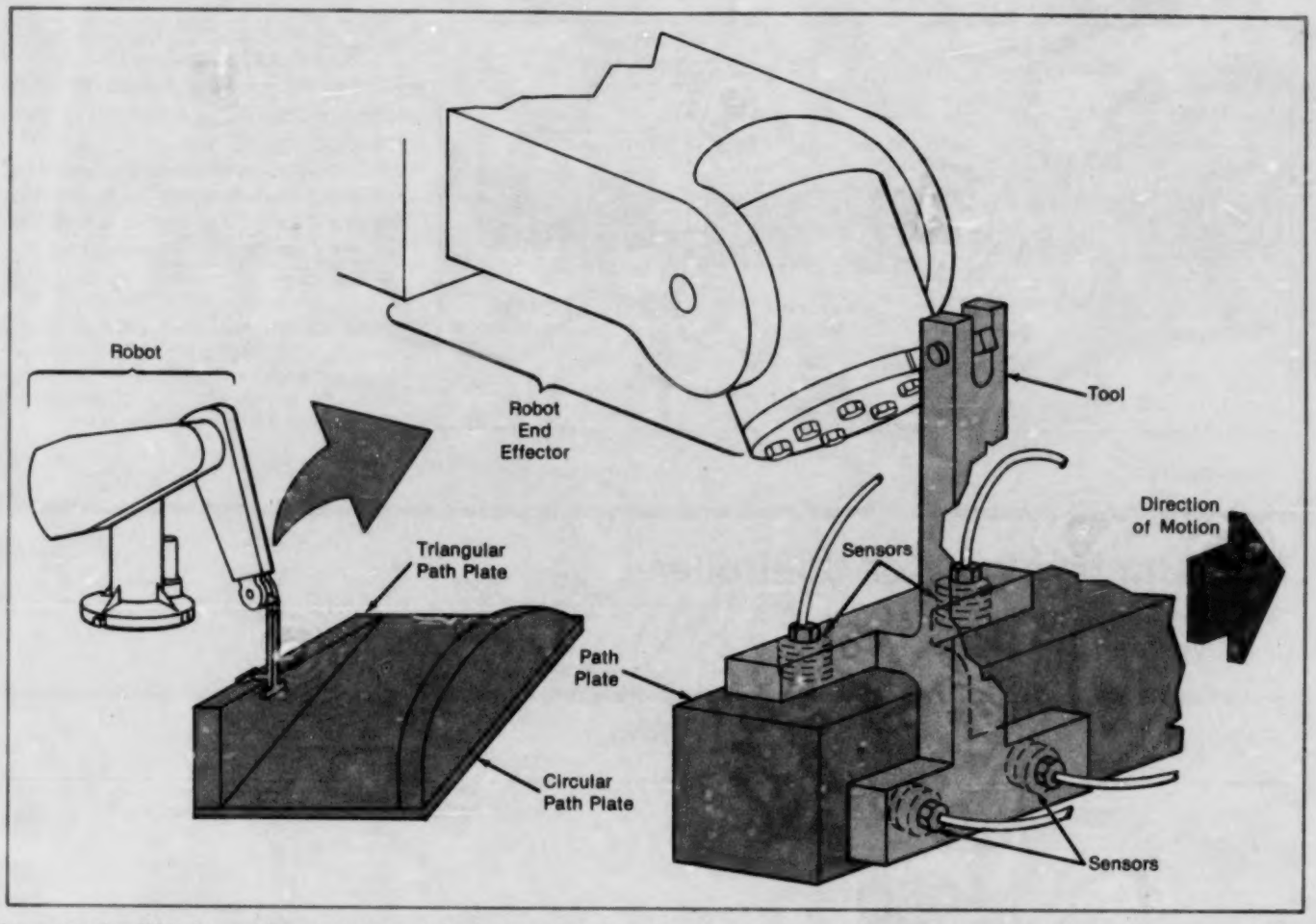
The accuracy and repeatability of continuous-path robot motion can be measured with a new test method. Until now, robot performance has been specified on a point-to-point basis. Point-to-point specifications, however, tend to be inadequate in describing such continuous-path operations as welding, sealing, and deburring.

The new method measures accuracy and repeatability at various speeds and loads within ±0.001 in. (25 μm). It determines the ability of a robot to maintain tool orientation. It can be used with almost any type of manipulator arm and with a separate, coordinated part positioner.

The robot end effector is directed to trace the contour of a path plate without contacting it (see figure). The end effector is fitted with a tool containing eddy-current sensors, which determine the separation of the tool or sensors from the path plate.

The robot is programmed to maintain a 0.045-in. (1.14-mm) separation between a sensor and the path plate, and the sensors are calibrated to produce zero output at that separation. A deviation from the programmed displacement appears as a negative or positive voltage at the sensor output terminals. An analog-to-digital converter transforms the sensor outputs (which can vary from −5 to +5 V) to digital form and feeds them to a portable computer for processing and storage.

The sensors are arranged in pairs on two perpendicular plates. They can thus measure the deviation in two perpendicular planes. The tool orientation can be determined from the outputs of the



Noncontacting Eddy-Current Sensors measure the distance from a tool to an aluminum path plate as a robot end effector moves the tool at a prescribed distance from the plate. Flat, sloped, curved, and other shapes can be used for the path plate.

two sensors on a given plate; any tendency for the tool to rotate appears as a difference in the two sensor outputs corresponding to the given rotation axis.

Path plates in a variety of shapes can be used. Triangular or circular-segment plates, in addition to the flat horizontal plate in the figure, can test a robot for its response to a variety of contours.

So that the tool speed can be measured, the aluminum path plate contains notches of a different material at precise intervals. The notches produce pulses in sensor output as a sensor passes over them. A deviation in the time between pulses represents a variation in speed.

This work was done by Timothy A. Allison and Gregory A. Arnold of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 45 on the TSP Request Card.*
MFS-29121

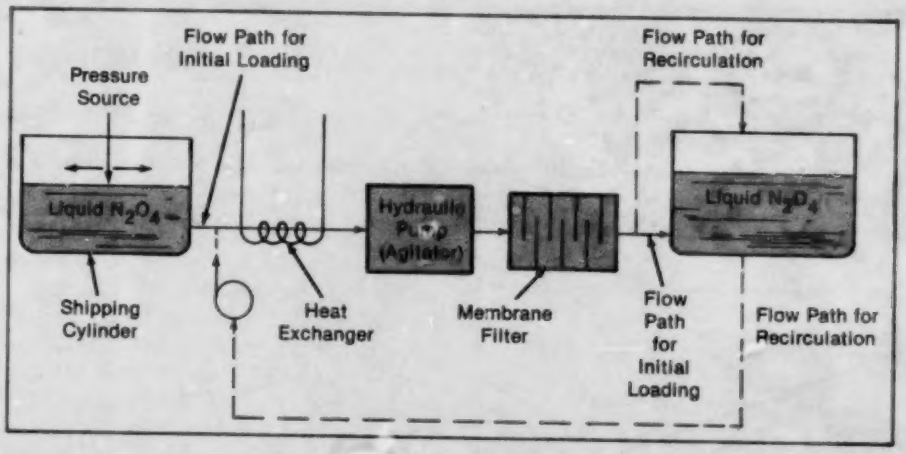
Cleaning of Liquid N_2O_4

This technique is useful in reducing the clogging of fluid lines.

Lyndon B. Johnson Space Center, Houston, Texas

A technique developed for cleaning of liquid N_2O_4 may be adaptable to the cleaning of a variety of industrial fluids, including fuels. Performance studies on the Space Shuttle vernier thrustor showed that the ratio of N_2O_4 oxidizer to fuel decreased during operation because of the deposition of metal (primarily iron) nitrates in the N_2O_4 line. This deposition occurred around the pressure-drop-trim orifice located between the valve outlet and the final injector-tube entrance. The iron nitrates presumably arose from the reaction of N_2O_4 with moisture and with iron from the mild-steel shipping containers. The precipitation of the nitrates apparently was a consequence of the pressure drop—such pressure drops were previously known to be among the factors causing the precipitation of nitrates from propellants saturated or supersaturated with iron.

The process for reducing metal nitrate concentration in liquid N_2O_4 is shown schematically in the figure. After being cooled to less than 40 °F (4 °C) in a heat exchanger, the liquid N_2O_4 is agitated through a hydraulic pump. The resulting precipitated nitrates are then removed by a very fine membrane filter. This process, used in filling the facility storage tank, is repeated several times by the recirculation of the stored N_2O_4 to remove as



much of the nitrates as possible.

This system typically lowers the iron content in liquid N_2O_4 from as high as 5.0 parts per million to about 2.0 or fewer parts per million.

This work was done by Gerald R. Pfeifer of The Marquardt Co. for **Johnson Space Center.** *For further information, Circle 97 on the TSP Request Card.*
MSC-20989

Metal Nitrate Impurities are precipitated from N_2O_4 by cooling the N_2O_4 in a heat exchanger and then passing it through a hydraulic pump. The precipitate is then removed by a fine membrane filter.

Two-Arm-Manipulator Controller

The controller provides 7 degrees of freedom in each arm.

Lyndon B. Johnson Space Center, Houston, Texas

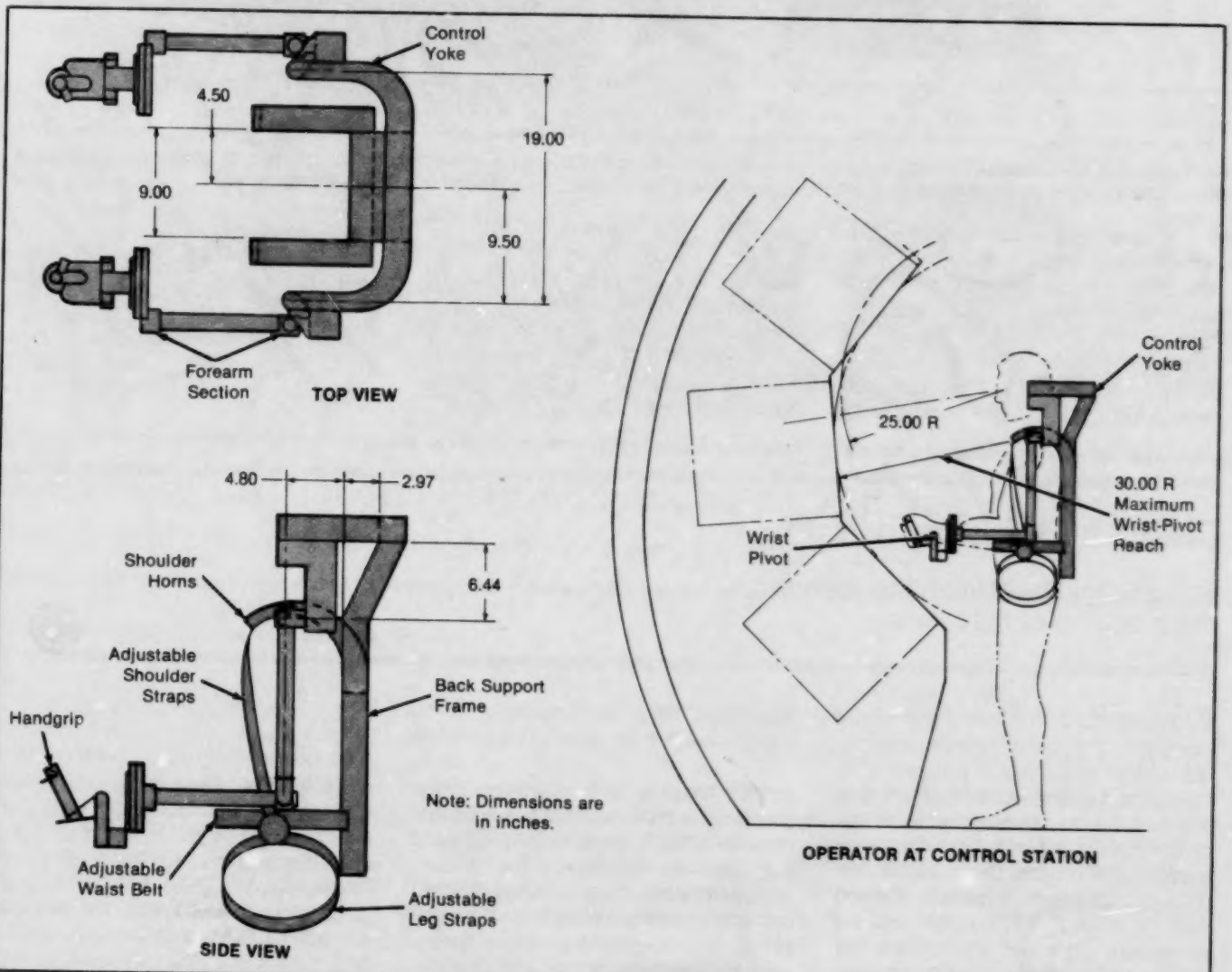
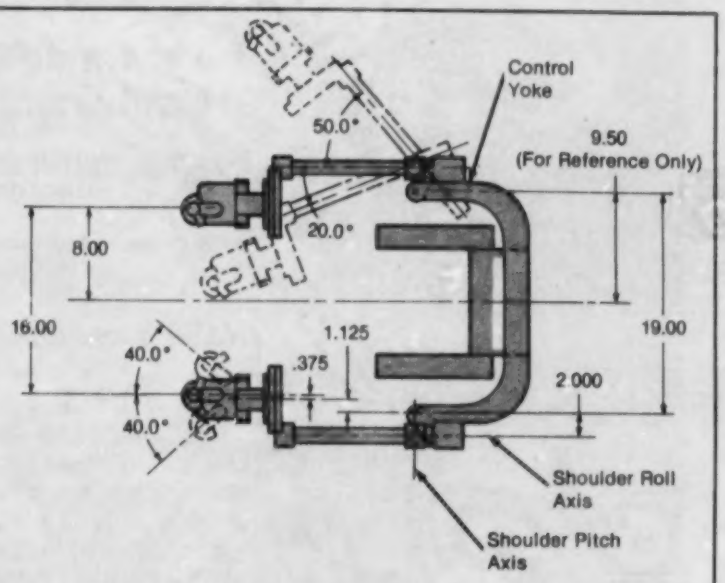


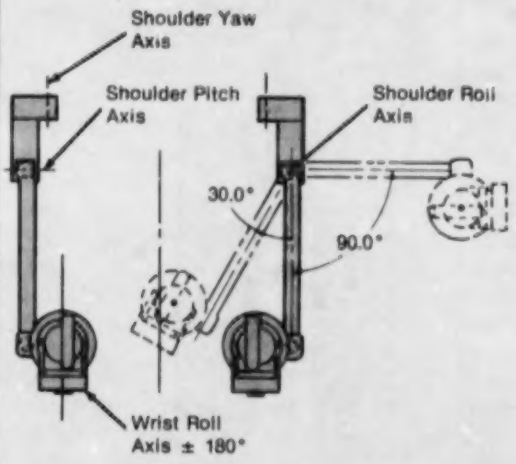
Figure 1. **Two Arm Mechanisms** of the controller are moved by the operator's arms and hands. The remote manipulator, located elsewhere, responds to the operator's arm and hand movements. Adjustable shoulder straps, a waist belt, and leg straps hold the harness securely on the wearer. The mechanisms and harness allow the operator to reach almost normally at a control station.

Master Degrees of Freedom in Angular Degrees

Shoulder	Pitch	+ 135, – 15
	Roll	+ 90, – 30
	Yaw	+ 50, – 20
Elbow	Pitch	± 45, – 75
Wrist	Pitch	± 45
	Roll	± 180
	Yaw	± 40

Note: Dimensions are in inches.





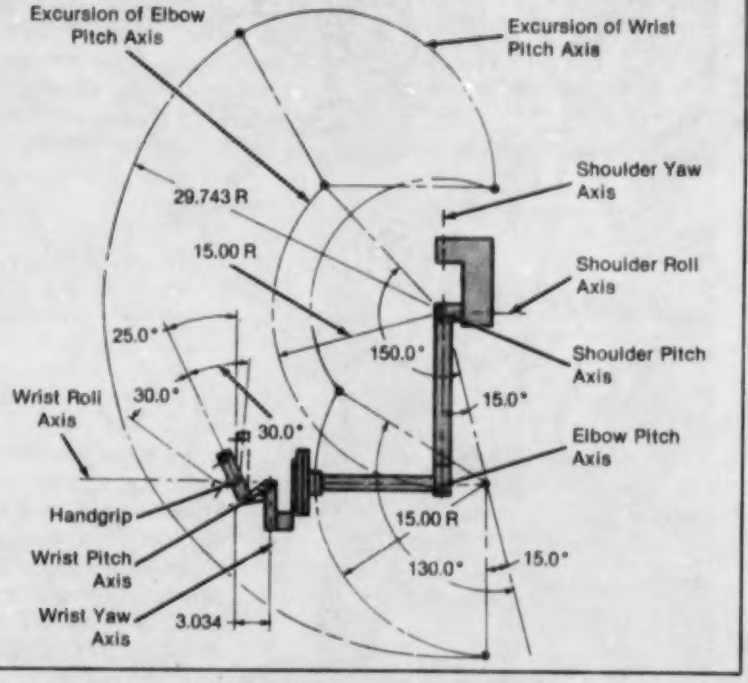


Figure 2. The **Control Motions** have the ranges indicated by the arcs and by the extreme mechanism positions.

A proposed shoulder harness would allow the wearer to control simultaneously and independently two remote manipulator arms and their end effectors. Each manipulator arm would have 7 degrees of freedom.

The harness would support manipulator-arm control mechanisms that are strapped to the operator's arms (see Figures 1 and 2). Each mechanism would include a wrist with 3 degrees of freedom, an elbow with 1 degree of freedom, and a shoulder with 3 degrees of freedom.

The wrist assembly would include a forearm roll ring that fits around the operator's wrist. A handgrip would transmit the operator's hand movements to the end effector. The forearm section may also be strapped to the operator near the elbow. The forearm and upper-arm sections would be adjustable in length to suit individual operators. The harness assembly would consist of a shoulder/neck yoke segment and a lower torso attachment with straps to fix the shoulder points relative to the operator.

This work was done by Stanis Coryell and Roy E. Olsen of Grumman Aerospace Corp. for **Johnson Space Center**. *No further documentation is available.*
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Toxic-Waste Disposal by Combustion in Containers

Chemical wastes would be burned with minimal handling in their storage containers.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed technique for disposing of chemical munitions by burning them inside their shells might be applied to the disposal of toxic materials stored in drums. This fast, economical procedure would overcome the heat-transfer limitations of conventional furnace designs by providing direct contact of oxygen-rich combustion gases with the toxic agent. There would be no need to handle the waste material, and the container would also be decontaminated in the process.

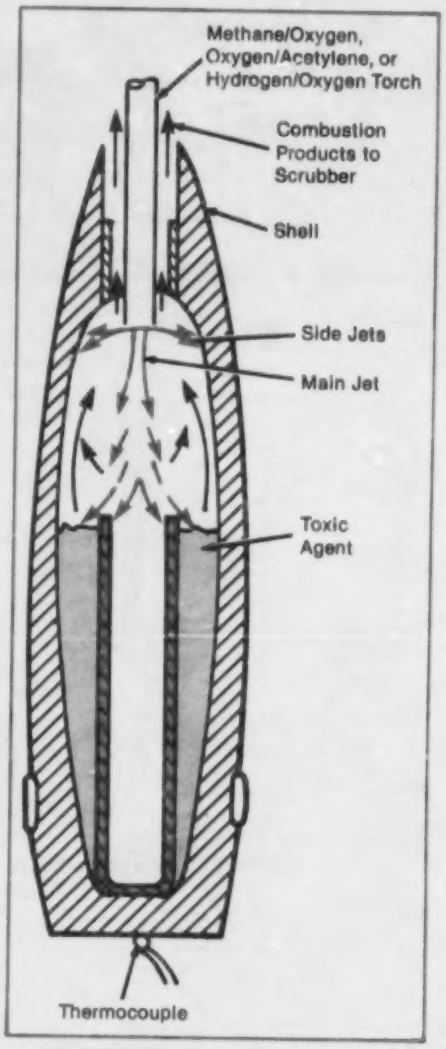
When an oxygen-rich oxygen/acetylene torch is inserted into the empty burster well of a chemical-agent shell (see figure), its side jets will cut the thin metal wall of the burster well. As the torch cuts through the metal, the liquid agent is exposed to the hot, excess-oxygen flame, which causes extremely rapid vaporization and combustion of the agent inside the shell.

As the torch moves down, it cuts more off the wall to expose more of the agent to the excess oxygen, thus ensuring complete combustion of the agent. It is envisioned that the reaction will be complete when the temperature of the outside surface of the shell reaches approximately 1,000 °F (540 °C), as indicated by a prepositioned thermocouple.

The side jets that make the initial cut into the burster well also serve as the equivalent of an afterburner, since they present a flame front through which the combustion products must pass before they can leave the shell. A relatively small exhaust scrubber can be used, since oxygen rather than air supports the combustion, resulting in a volume reduction by a factor of approximately 5.

There are many possible variations of the in-shell combustion theme: The vaporization, combustion, or afterburning steps could involve acetylene/air, oxygen/hydrogen, methane/air, plasma, or laser (pyrolysis), while burster-well breaching could involve oxygen/hydrogen or plasma torches, electric discharges, lasers, or mechanical dies.

It is estimated that the agent within a round can be completely burned out in a few minutes. An obvious advantage is that the agent is contained within the munition or other container until the moment of destruction.



An Oxygen-Rich Torch Flame cuts the burster well and then causes the vaporization and combustion of the toxic agent contained in the shell.

This work was done by John Houseman, James B. Stephens, Philip I. Moynihan, Leslie E. Compton, and John J. Kalvinskas of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 6 on the TSP Request Card.*

NPO-16710

Toxic-Waste Disposal by Drain-in-Furnace Technique

The compact furnace could be moved from site to site.

NASA's Jet Propulsion Laboratory, Pasadena, California

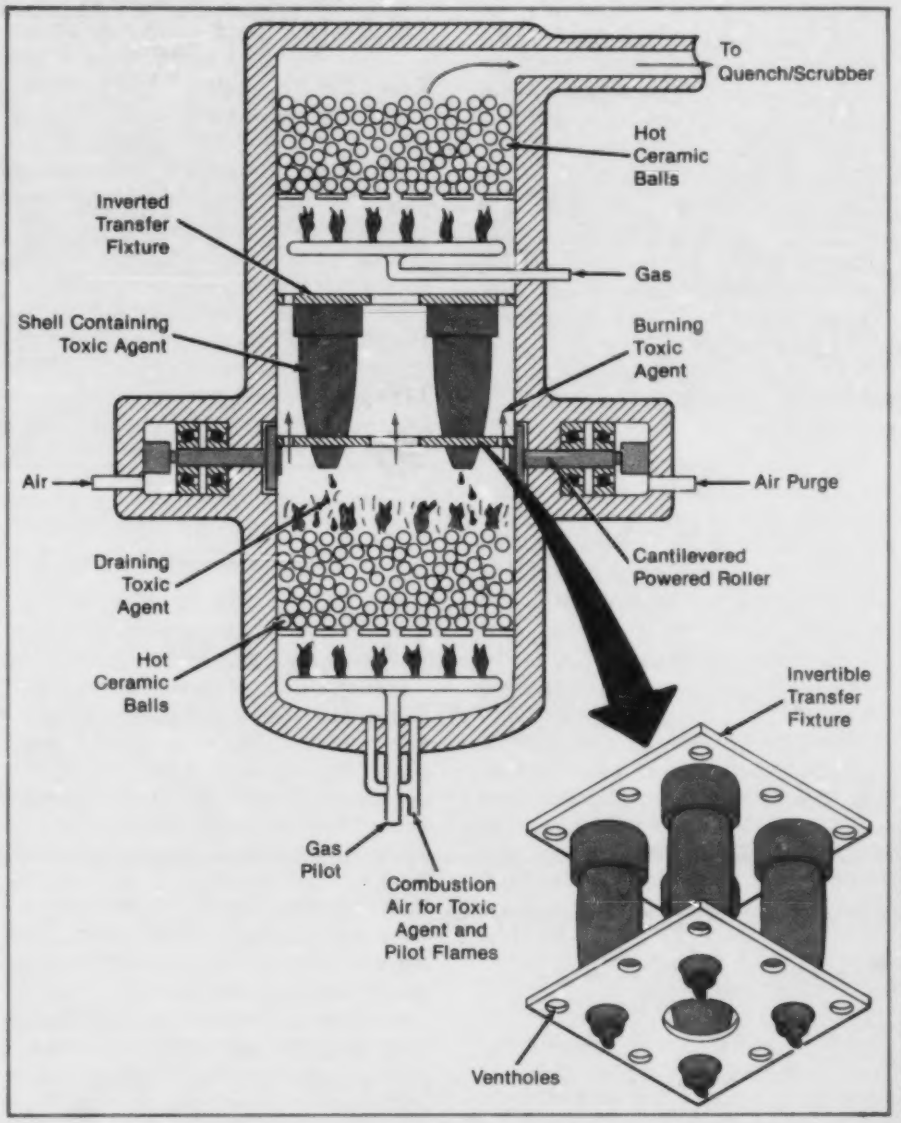
Toxic industrial wastes could be destroyed using a furnace concept developed for the disposal of toxic munitions. In this procedure, the toxic waste would be drained into the furnace where it would be incinerated immediately.

In the case of chemical munitions, first the burster well would be breached with a perforating mandrel, then temporarily resealed with a low-melting-point wax plug. Then the munition would be inverted in the furnace (see figure), and the gas fires ignited. The hot combustion gases would melt the wax plug, allowing the agent to drain quickly from the munition. The remaining thin liquid film of the agent would be vaporized quickly when the temperature of the shell wall reaches its boiling point.

As the liquid agent flows from the inverted munition onto the lower bed of hot ceramic balls, it would be spread into a thin film of large surface area. Here it would be ignited by hot combustion air and gases rising through the ceramic balls from the natural-gas burner. The resulting flames and hot combustion gases would pass directly upward over the munition, thus causing its own combustion to heat it directly. Eleven percent of the heat of combustion of the 6 lb (2.7 kg) of agent VX in a typical 100-lb (45.4-kg) round would suffice to raise the temperature of the shell to 1,000 °F (538 °C).

Immediately above the main furnace would be an afterburner, which would incorporate hot ceramic balls, possibly coated with a combustion catalyst, to destroy any remaining agent by providing additional residence time at high temperature. Combustion would be continued until the exhaust-gas sampler no longer detects any traces of agent and the shell-wall temperature has reached 1,000 °F (538 °C). The gas flame would then be turned off and the shell transfer fixtures removed from the chamber.

The small combustion chamber would have fireproof doors at its entry and exit side. Between combustions, the munitions set in transfer fixtures would be moved into and out of the chamber by a guideway of powered rollers. Roller guideways are simple and reliable and would not present any sealing problems in the air locks.



In the **Furnace** the toxic agent is rapidly drained and destroyed in the small combustion chamber between upper and lower layers of hot ceramic balls.

It is estimated that an overall cycle time of 20 min can easily be achieved. A total of ninety 155-mm rounds per batch could be processed in a combustion furnace/afterburner combination 3 ft wide by 8 ft high by 24 ft long (0.9 m wide by 2.4 m high by 7.3 m long). Such a furnace could be mounted on a 10- by 40-ft (3- by 12-m) trailer that could be moved from site to site, as could the deburstering and scrubbing equipment.

This work was done by Leslie E. Compton, James B. Stephens, Philip I. Moynihan, John Houseman, and John J. Kalvinskas of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 38 on the TSP Request Card.*

NPO-16579

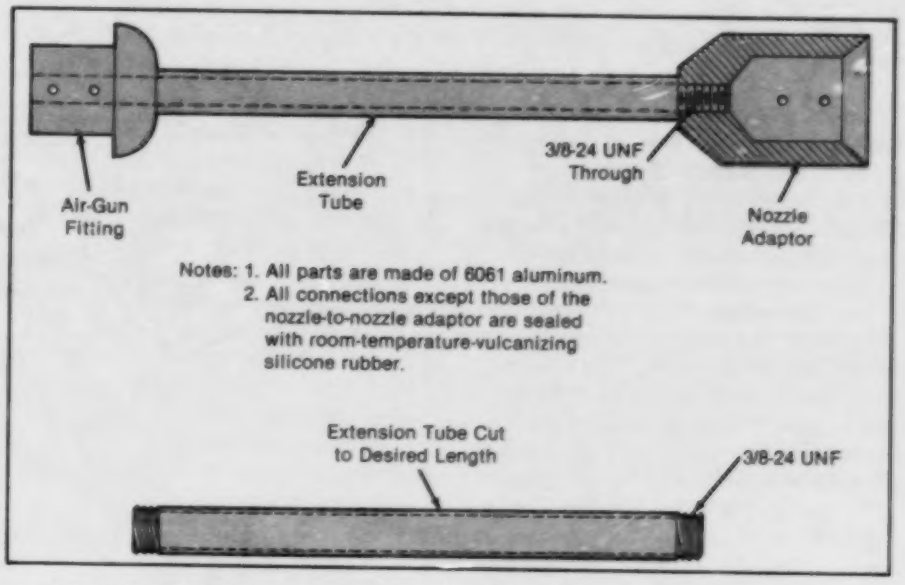
Nozzle Extension for Safety Air Gun

A conical airstream at the end of the extension protects the operator from blowback.

Langley Research Center, Hampton, Virginia

Safety air guns are used for the removal of chips from machined parts during the machining process to prevent unnecessary heat and wear on cutting tools and to improve the quality of parts. On a numerically controlled machine, an extended nozzle is required on the air gun to remove chips without putting the operator dangerously close to the rotating spindle and cutting tool. Previous modifications to extend the nozzles of the commercially available safety air guns in use at Langley Research Center were considered unsafe because the modifications failed to provide back-pressure relief and a conical airstream to prevent chips from being blown back at the operator.

A new nozzle-extension design overcomes these problems and incorporates the original commercial nozzle, thereby retaining its intrinsic safety features. The components include an extension tube, the length of which can be made to suit the application; the adaptor fitting (which, in place of the safety nozzle, is pinned and sealed into the air gun); and the nozzle adaptor, into which the safety nozzle is repinned to maintain the original safety features. The extension tube is threaded and sealed into the adaptor fitting at one end and into the nozzle adaptor at the other end, as shown in the figure.


Air-Gun Fitting
Extension Tube
3/8-24 UNF Through
Nozzle Adaptor
Notes: 1. All parts are made of 6061 aluminum.
2. All connections except those of the nozzle-to-nozzle adaptor are sealed with room-temperature-vulcanizing silicone rubber.
Extension Tube Cut to Desired Length
3/8-24 UNF

The **Nozzle Extension** helps to blow machine chips away from the operator.

This design moves the conical airstream to the end of the extension to blow machine chips away from the operator. This nozzle-extension modification allows the safe and efficient operation of machine tools while maintaining the integrity of the original safety-air-gun design.

This work was done by Henry N. Zumbrun and Delwin R. Croom, Jr., of **Langley Research Center**. *No further documentation is available.*
LAR-13366

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Coal-Based Fuel-Cell Powerplants

Alternative plant designs are evaluated.

A report assesses advanced technology design alternatives for integrated coal-gasifier/fuel-cell powerplants. Various gasifier, cleanup, and fuel-cell options are evaluated, in part by assessment of the technical assumptions used in the design studies and the status of development of proposed technology alternatives. The evaluation includes adjustments to the assumed performances and costs of proposed technologies where required. The analysis identifies uncertainties remaining in the designs and the most promising alternatives and the research and development required to develop these technologies.

The bulk of the report is a summary and detailed analysis of six major conceptual designs and variations of each. All designs are for a plant that uses Illinois No. 6 coal and produces 675 MW of net power. These plant designs are compared to a reference design that includes an oxygen-blown gasifier, a solvent process for gas cleanup, and a molten-carbonate fuel cell. Power is produced in the expansion turbines, the fuel-cell modules, and a conventional steam cycle. The system efficiency of this design is 48.7 percent.

Of the alternative plant designs, two apparently would generate the electricity cheaper than the reference design would provide. When the entrained-bed gasifier and the low-temperature gas-cleanup system of the reference are replaced by a fluidized-bed gasifier and a hot gas-cleanup system, respectively, the unit cost of electricity is reduced by 4 percent.

The most promising design includes a fluidized-bed gasifier, zinc/ferrite high-temperature gas cleanup, and a pressurized solid-oxide fuel cell. Coal is fed with air and steam to the gasifier. The gasifier effluent is cooled to generate steam, then sent to the gas-cleanup unit. The clean gas is expanded and fed to the fuel cell along with preheated and compressed air.

The fuel-cell exhaust gases are combined in an afterburner that preheats the incoming air. A turbocompressor compresses the fuel-cell and gasifier air and generates power. Turbine exhaust is cooled in steam generators and an economizer before being released to the atmosphere. The steam is used in the steam cycle to produce power.

A plant built according to this design would produce electricity at a unit cost of 91 percent of that of the reference system. A unique feature of this design is the choice of low fuel use in the fuel cell and the ability to use gas turbines at high inlet temperatures.

This work was done by Joseph F. Ferral, Alfred W. Pappano, and Charles N. Jennings of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Assessment of Technology Alternatives for Coal-Based Fuel Cell Power Plants," Circle 24 on the TSP Request Card.*
NPO-16543

Lifetimes and Reliabilities of Bevel-Gear Drive Trains

Statistical methods are used to predict system lifetimes from component lifetimes.

A NASA-Lewis report presents a life and reliability model for bevel-gear drive trains. Bevel-gear and support-bearing lives are analyzed for each gear and bearing in the drive train, with the results statistically combined to produce a system life for the entire drive train. A numerical example is included.

Experimental testing programs are normally used by industry to evaluate different gearbox designs. These programs include real-time duty-cycle simulation and overload tests. These tests provide an important proof test for proposed designs but are extremely costly in terms of time and resources. Analytical life models are needed in order that only optimal designs are actually tested.

A life and reliability model is presented for bevel-gear drive trains, based on the pitting-fatigue life of the components of the system. The components include the driving and driven bevel gears and the support bearings. The drive train may have a single input gear or dual input gears of equal size. The gears may be straddle mounted or supported in a bearing quill. The loading on the gear train is specified by the use of a mission spectrum consisting of loads and time-at-loads.

The bearing fatigue life is determined using the classical Lundberg-Palmgren theory. The Lundberg-Palmgren theory has been adapted to predict the bevel-gear life. Both the bearing and gear lives follow the Weibull failure distribution. The report shows how to use this information to determine the system life of the drive train, using the methods of probability and statistics. The basic dynamic capacity, defined as the output torque that may be applied for one million output rotations with a 90-percent probability of survival, is also developed.

A numerical example is included in the report. The life distributions for the components are plotted. The system life is plotted on Weibull coordinates and also plotted against the load.

This work was done by D. G. Lewicki and J. J. Cox of **Lewis Research Center** *and M. Savage and C. K. Brikmanis of the University of Akron. Further information may be found in NASA TM-87006 [N85-27227/NSP], "Life and Reliability Modeling of Bevel Gear Reductions."*

Copies may be purchased [prepayment required] from National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14372

Interchangeable Tools for Remote Manipulators

Remote manipulators could handle a variety of maintenance and assembly jobs.

A report presents concepts and specifications for a set of interchangeable end-effector tools. The tools would be used on a remotely operated manipulator to work on satellites in orbit. Such tools, for example, would make urgent repairs, do routine maintenance, transfer fluids, construct and assemble satellites, and deploy and retract appendages. With modifications, the tool concepts and the systematic approach to tool design should be applicable to such terrestrial uses as industrial robots, manually operated tools, and safety equipment.

The tool set covered in the report includes the following:

- Rotary power tools with attachments,
- A fluid-connector mating and demating tool,
- An explosive-shearing tool,
- An electrical-connector mating and demating tool,
- A general-purpose grappler,
- A power spreader,
- An unpowered pry bar,
- A hole-punching and riveting tool, and
- Special grips and jaws.

The report examines the in-orbit maintenance needs of satellites planned for launching from the mid-1986 through the year 2000. It reviews criteria for selecting members of a set of tools to meet these needs. It describes the tools and tabulates the various operations that each can perform. It presents dimensions and performance specifications for each and explains how each would be operated and controlled. Finally, the report discusses a concept for a tool-storage system that would hold the tools securely when they are not used but kept accessible to the manipulator. Drawings attached to the report illustrate the general shapes and sizes of some of the conceptual tools.

This work was done by Joseph C. Cody of SRS Technologies for **Marshall Space Flight Center**. *To obtain a copy of the report, "Interchangeable End Effector Tools Utilized on the PFMA — Task 1 Final Report," Circle 76 on the TSP Request Card.*

Inquiries concerning commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center *[see page 29].* *Refer to MFS-27125.*

Solar Thermal Rocket Propulsion

Heating a propellant with concentrated Sunlight is considered.

A paper analyzes the potential of solar thermal rockets as a means of propulsion for planetary spacecraft. A solar thermal rocket uses concentrated Sunlight to heat a working fluid, which is expelled through a nozzle to produce thrust.

This paper presents an analysis of solar thermal rocket mission performance on the basis of transfer characteristics, which describe any one of a number of solar thermal thruster concepts. It considers the thermal control of the liquid hydrogen propellant (chosen because it enables the maximum specific impulse), the propellant-feeding system, and the system mass. The report compares the performance of solar thermal rocket propulsion with electric propulsion based on arc-jet or ion engines for the completion of missions to Saturn and Uranus.

The paper finds that solar thermal propulsion can be useful in future missions of planetary exploration. The performance of solar thermal rocket propulsion can be comparable to that of electric propulsion when used with the Space Shuttle and a Centaur G′ upper stage for injecting

payloads into transfer trajectories. Both electric and solar thermal propulsion would shorten the travel time to Saturn and Uranus considerably below that for chemical propulsion.

The paper describes a solar thermal propulsion concept based on solar collectors that rotate to orient themselves toward the Sun to enable the generation of thrust in any direction. A planetary spacecraft would be launched from the Space Shuttle with the Centaur and solar thermal stages. The Centaur would provide the initial acceleration and then would separate. The solar thermal stage would then deploy and operate for about a month to place the spacecraft in its final trajectory.

This work was done by Joel C. Sercel of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Solar Thermal Propulsion for Planetary Spacecraft," Circle 110 on the TSP Request Card.*
NPO-16654

Studies of Pilot-Induced Oscillation

The Total In-Flight Simulator permits reliable evaluation of landing characteristics of aircraft with PIO.

Four types of flight simulators were used to study a pilot-induced oscillation (PIO) that had been observed during one approach and landing test of the Space Shuttle. In addition to describing the test results, a report discusses the simulation requirements for investigating PIO characteristics and includes an evaluation of the relative merits of the simulators. These observations should be of interest to those studying landing characteristics of other aircraft and to those designing pilot-training programs.

The general conclusion is that in-flight simulation is the only reliable method of evaluating the landing characteristics of aircraft with PIO tendencies; even then, some form of artificial task needs to be introduced to produce a pilot workload similar to that encountered in an actual landing. However, the report also describes a simpler fixed-base simulation of a tracking task that correlates well with the landing task and which can be used in the development of control systems.

The Space Shuttle was simulated with a fixed-base ground simulator, two moving-base ground simulators, and an in-flight simulator. The moving-base facilities were the Flight Simulator for Advanced Aircraft and the Vertical Motion Simulator, both at Ames Research Center. The in-flight simulation was performed on the Total In-Flight Simulator. Additional studies on the effect of time delay were performed on the F-8 digital fly-by-wire airplane at Ames.

The report includes diagrams of the rating scales used by the pilots to describe handling characteristics in general. The distribution of pilot ratings under various tests conditions is shown in a series of 18 bar graphs. For the F-8 studies, two graphs show the pilot ratings as a function of time delay over the range of 125 to 300 ms for landings with high- or low-workload tasks and for a tracking task (simulated tracking for in-flight refueling). The tracking test results fall between the lines for the high- and low-workload tasks.

The closed-loop response characteristics in the tracking task are a function of the pilot gain and lead compensation and of the distance from the tracking aircraft to the target. By adjusting the distance variable and the time available for accomplishing the task in the fixed-base simulation, the closed loop PIO frequencies seen on the simulator could be matched to those observed in the Shuttle landing tests. This provides a convenient way to reproduce PIO conditions and makes it possible to evaluate control-system changes with a relatively simple simulation. It should be noted, however, that this technique is useful mainly for evaluating PIO characteristics that have already been observed in flight, inasmuch as the actual oscillation frequencies are required for the simulation. The report includes seven references to previous work in the field.

This work was done by Bruce G. Powers of **Ames Research Center**. *Further information may be found NASA TM-86034 [N84-20566/NSP], "Space Shuttle Pilot-Induced-Oscillation Research Testing."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11601.

Properties of Combustion Gases

New reports include graphs to facilitate the use of combustion data.

Computations have been made to determine the equilibrium properties of the gaseous products resulting from the combustion of ASTM Jet A fuel and dry air and natural-gas fuel and dry air. During combustion reseach, it is important that the properties of combustion gases be readily available and in a form that is convenient and useful to the designer and researcher.

In the past, the combustion-gas properties of gas-turbine fuels, as well as of a variety of other hydrocarbon fuels, have been computed and reported. These reports have been used extensively at NASA and throughout industry. The computational schemes that have been developed over the years by Huff, Gordon, Zeleznik, and McBride form the basis for these reports and have been used to compute combustion-gas properties for a wide spectrum of fuel and oxidant combinations. Often, however, the tables and charts have not been prepared for specific fuels. The data, for example, are in a tabular form for hydrogen/carbon ratios of 1.7, 2.0, and 2.1 for a range of assigned pressures, temperatures, and fuel/air mixtures.

In a new series of reports, the computed data also include combustion thermodynamic properties for a range of inlet-air temperatures, but these data are plotted to facilitate their use. The resulting figures have proved to be extremely useful in combustion research, and copies of such figures have been prepared for a wide variety of fuels. A new series of figures and tables, which extend the applicable range of the parameters, has been published. The first report of this series lists data from the combustion of ASTM Jet A fuel and dry air.

The second report presents tables and figures for the combustion-gas properties of natural-gas fuel and dry air for pressures from 0.5 to 50 atm (5×10^4 to 5×10^7 Pa), inlet-air temperatures from 250 to 1150 K, and equivalence ratios from 0 to 2. A complete set of tables and figures is provided on four microfiche films supplied with the report.

This work was done by Jerrold D. Wear, Robert E. Jones, Arthur M. Trout, and Bonnie J. McBride of **Lewis Research Center**. *Further information may be found in:*

NASA TP-2359 [N85-10064/NSP], "Combustion Gas Properties I -ASTM Jet A Fuel and Dry Air" and NASA TP-2435 [N85-21168/NSP], "Combustion Gas Properties II -Natural Gas Fuel and Dry Air."

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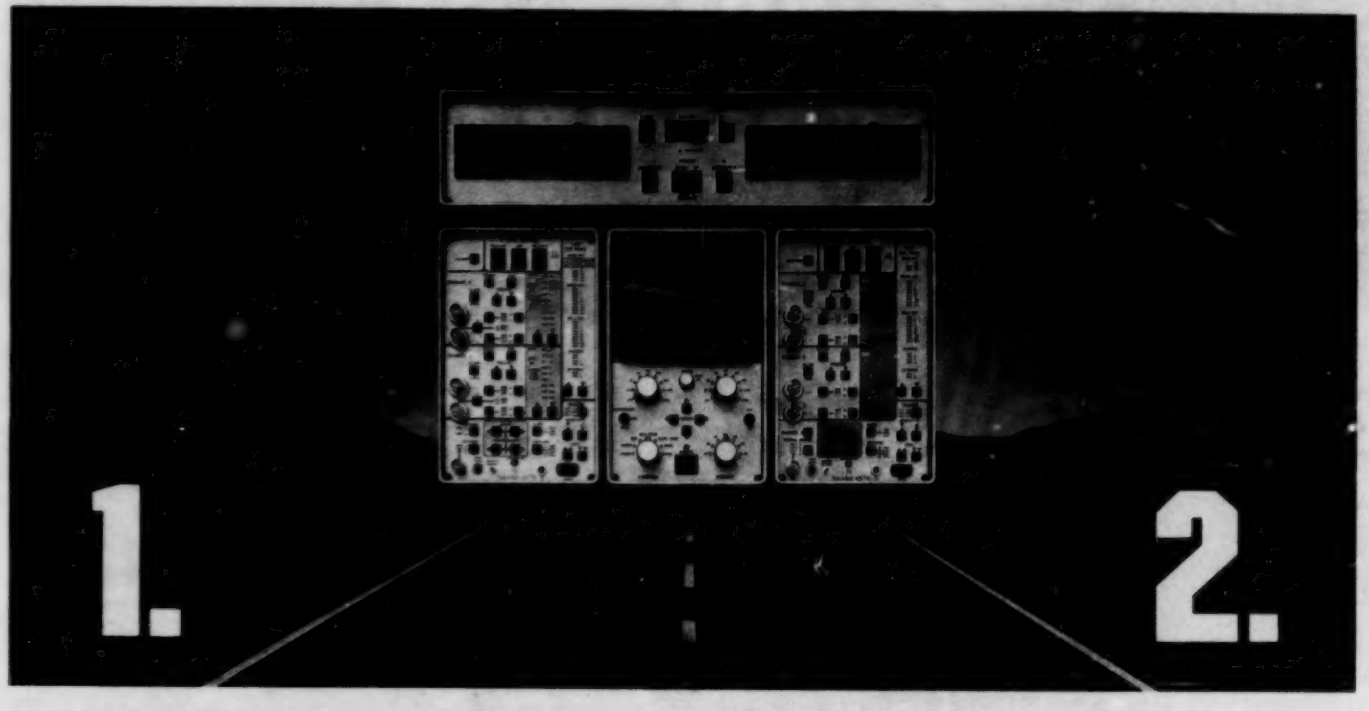
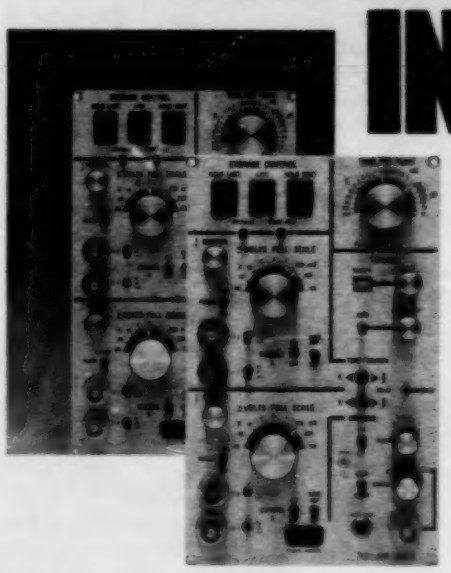
LEW-14275

THE FIRST NAME IN DIGITAL SCOPES



TWO DIGITAL SCOPES IN ONE.



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Telescoping Space-Station Modules

The "module-within-a-module" design doubles usable space.

Langley Research Center, Hampton, Virginia

Current plans regarding the construction of a permanently-manned orbiting space station include the use of the Space Shuttle to deliver modules to orbit. These modules will provide living quarters for the space-station crews and will house experimental and fabrication equipment. To minimize transportation requirements, the space-station capability delivered per Shuttle launch must be maximized.

A new telescoping-space-station design for achieving this goal involves essentially a module within a module. After being carried to orbit within the payload bay of the Space Shuttle orbiter, the outer module would be telescopically deployed to achieve nearly twice as much usable space-station volume per Space Shuttle launch as would be otherwise achieved. Also, by retracting the outer module over the inner module, significantly enhanced protection against space debris and radiation could be achieved.

The basic module-within-a-module assemblage is shown in Figure 1. Two such assemblages could fit easily within the Space Shuttle orbiter payload bay with additional volume and payload to spare. There are two options regarding module pressurization. One is to vent the entire assemblage from ground to orbit and then pressurize in orbit. The other is to pressurize the inner module to 30 psia (200 kN/m^2) prior to launch and, through expansion of the assemblage at the station and equalization of the compartment pressures, provide the standard 14.7 psia (100 kN/m^2) initial atmosphere.

Closed-loop or "race-track" space-station configurations (see Figure 2) are possible with this concept and provide additional benefits. One benefit involves making one of the modules a double-walled haven safe from debris, radiation,

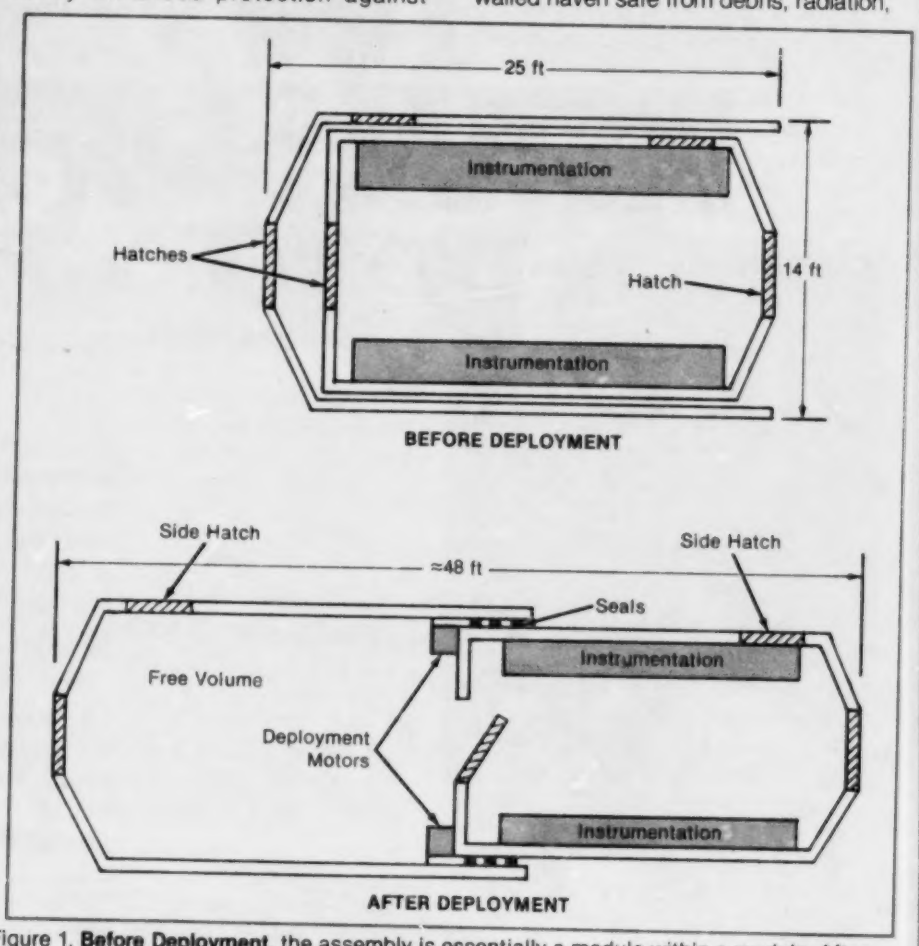


Figure 1. **Before Deployment,** the assembly is essentially a module within a module. After deployment, the available space is approximately doubled.

and the like. This module would be accessible from either end, and hence readily available to all positions in the space station.

The telescoping nature of the modules lends the concept to variations in space-station configuration, assembly, and disassembly. Adaptations of the concept could also provide flexibility in the methods in which the Space Shuttle orbiter is docked or berthed with the space station and decrease the chances of damage because of accidental contact between the station and the orbiter during these maneuvers.

This work was done by Robert D. Witcofski of **Langley Research Center**. *For further information Circle 63 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13330.

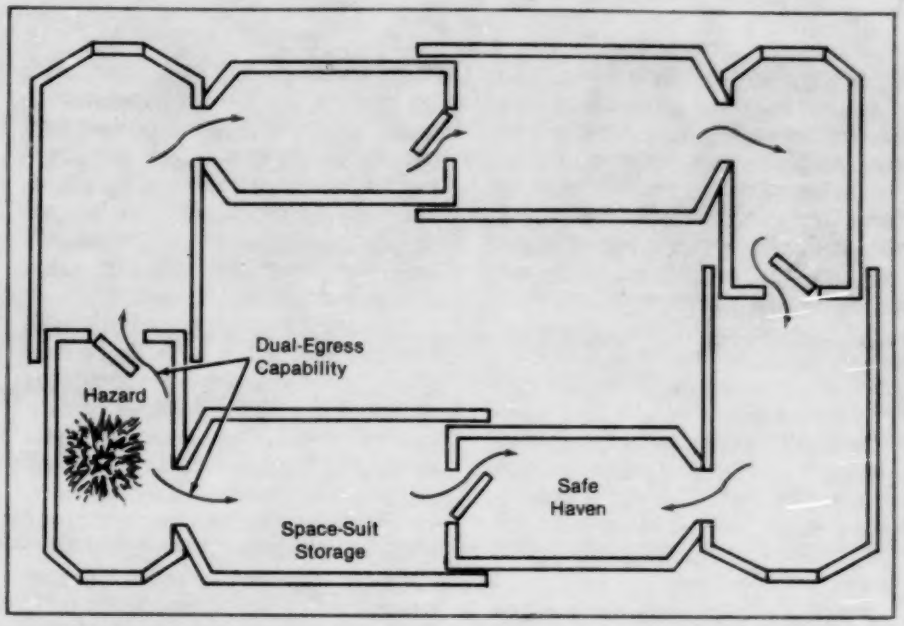


Figure 2. The **"Race-Track" Configuration** provides additional benefits, including an accessible safe haven.

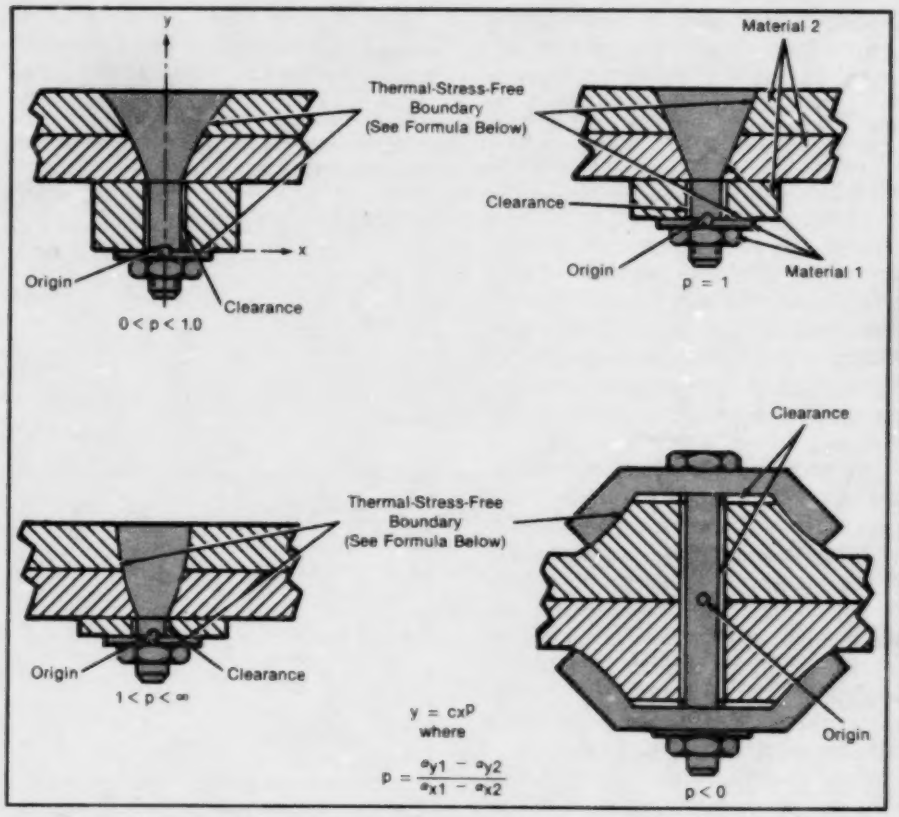
Thermal-Stress-Free Fasteners for Orthotropic Materials

Two-dimensional analysis defines the shapes of interfaces between materials.

Langley Research Center, Hampton, Virginia

A common method of attaching structural components in aerospace systems is by riveting or bolting. If the rivet or bolt is made from a material with a coefficient of thermal expansion substantially different from those of the components being attached, then it is possible to encounter fairly high thermal stresses (or, conversely, a loose joint) if the temperature is increased or decreased significantly. In the case of metal components, this is generally not a problem, because the rivet or bolt is made from the same or a similar alloy. However, with structures made from composite materials, it is difficult to fabricate fasteners from the same material. Also, structural metals are generally isotropic; that is, the thermal-expansion coefficient is the same in all directions. Composite materials, on the other hand, are often anisotropic. Hence, when riveted composite materials heat up or cool down, the rivets can come loose or be subjected to high compressive stresses. Even the state-of-the-art DAZE conical fastener, which by its unique geometry can successfully join isotropic materials with dissimilar rivets, has found only limited application with composites, because most composites are not isotropic.

A theoretical basis for the design of thermal-stress-free fasteners has been de-



Thermal-Stress-Free Joints can be made in a variety of configurations, depending upon the thermal-expansion characteristics of the materials.

veloped. The analysis yields the equation of a two-dimensional thermal-stress-free interface between two materials with orthotropic coefficients of thermal expansion. If both materials have coefficients of thermal expansion that are isotropic in one plane, the two-dimensional analysis can be used to design thermal-stress-free fasteners, made from one material, which are used to join pieces of the other material. The two materials remain in contact as the temperature increases, forming a tight joint without interference and providing effective shear transfer. The simplest general shape is an axisymmetric, curved-side fastener. If the exact shape of the thermal-stress-free fastener is nearly conical, it can be approximated by a conical fastener with the vertex slightly offset.

Several types of thermal-stress-free joints are shown in the figure. The material being joined (material 2) has unequal thermal coefficients of expansion (COE) in the inplane and thickness directions, denoted in the figure as α_{x2} and α_{y2}, respectively, which also differ greatly from the inplane and thickness COE's of the fastener material (material 1), α_{x1} and α_{y1}, respectively. These conditions will cause adverse thermal stresses or looseness in the joint if conventionally shaped fasteners are used. This design technique determines fastener shapes that will maintain a tight thermal-stress-free joint while the joint undergoes a uniform temperature change.

The equation defining the initial interface shape is shown in the figure as a power curve in which the exponent is dependent on the COE's of the fastener (material 1) and of the structural material (material 2). Suitable minimum and maximum fastener diameters are obtained by varying the washer thickness of material 2 and the coefficient of the power term. Varying the COE values results in shapes having either negative curvature ($0< p<1$), conical shapes (the shape of the DAZE fastener with $p = 1$), positive curvature ($p>1$), or a negative slope with negative curvature ($p<0$). A steel fastener designed to join pieces of graphite survived four thermal cycles to 1,600 °F (870 °C), whereas a conventional fastener failed after only one cycle, demonstrating the validity of this concept.

This work was done by Max L. Blosser and Robert R. McWithey of **Langley Research Center** *and Thomas F. Kearns of the Institute for Defense Analyses. Further information may be found in NASA TP-2226 [N84-13614/NSP], "Theoretical Basis for Design of Thermal-Stress-Free Fasteners."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13325

Modular Firewalls for Storage Areas

Honeycomb ablative structures are assembled in place as needed.

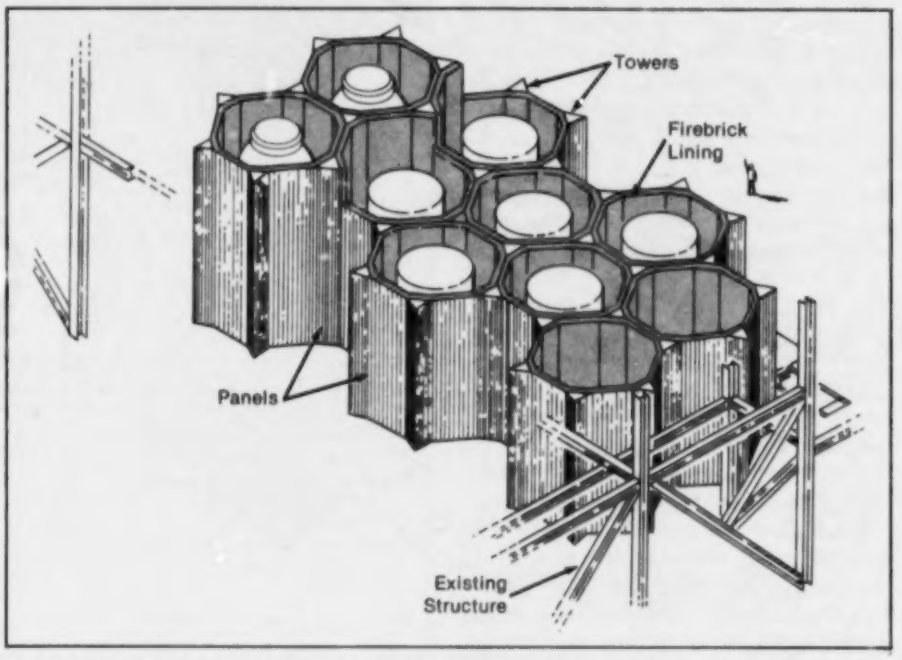
John F. Kennedy Space Center, Florida

A portable, modular barrier withstands the heat of combustion for a limited time and confines the combustion products horizontally to prevent fire from spreading. The barrier absorbs the heat energy by ablation and is not meant to be reused. Designed to keep fires from spreading among segments of solid rocket propellant in storage, the barrier could also be erected between storage units of other flammable or explosive materials — for example, tanks of petroleum or liquid natural gas. Since few common materials have heating values or energy-release rates as high as those of rocket propellants, the barrier should be adequate for most industrial purposes.

For an economy of material and space, the barrier is laid out on a hexagonal floor plan and resembles a honeycomb (see figure). Steel triangular towers are placed at the hexagon corners to support the 8- by 12-ft (2.44- by 3.66-m) steel-skeleton panels of the honeycomb-cell walls. Cells are added horizontally to cover the required floorspace. The structures can also be stacked vertically in 12-ft (3.66-m) units to a maximum cell height of 60 ft (18.29 m).

Each tower is made of three 5-in. (12.7-cm) pipes laterally supported by 6-in. (15.2-cm) I-beams and braced by ¾-in. (19.05-mm) rods. The panels are lattices of variously sized beams braced by rods.

After the steel skeleton is erected, the structure is lined with firebricks. Each brick is about 6 by 9 by 3 in. (15.2 by 22.9 by 7.5 cm) and is molded with tabs that interlock with the steel framework. The bricks are stacked with the 6-in. dimension as the insulating-wall thickness. The bricks can be placed on either or both panel faces and on any or all tower faces.



Giant Honeycomb Structures are assembled in modular units. Flammable materials are stored in the cells. The walls are insulated with firebrick to prevent the spread of fire among the cells.

The insulating firebrick material is a porous clay less than half as dense as conventional firebrick. Some types can withstand 1,538 °C for an indefinite time. The hot face can be exposed briefly to 2,760 °C. At this temperature, it ablates; but until ablation is nearly complete, it does not lose strength or transmit excessive temperature to the opposite face. The walls are designed to withstand a maximum combustion pressure of 540 lb/ft^2 (26 kN/m^2).

This work was done by Otto H. Fedor and Lester J. Owens of **Kennedy Space Center**. *For further information, Circle 88 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11276.

Faster Edge-Defined Silicon-Ribbon Growth

End-cooling may allow faster growth and may yield single-crystal ribbons.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed improvement in the edge-defined film-fed process for growing silicon ribbons should increase the speed of growth and improve the quality of the silicon product. The improved process may also produce silicon sheets, webs, or boules.

To maintain the growth of a silicon ribbon, the liquid silicon emerging from the die must be solidified by cooling within the maximum height that the liquid meniscus can extend above the die before collapsing. For a 0.15-mm-thick sheet, this height is more than 8 mm on the sides but only about 1 mm at the ends.

In the current process, the molten silicon emerging from the die is solidified with the help of two cold shoes placed on opposite sides of the ribbon (see Figure 1). The speed of growth is very limited. Experience has shown that whenever the upper pulling-speed limit is reached, the growth of the ribbon is terminated by the collapse of the meniscus at one of the ends. The silicon-ribbon product is mainly polycrystalline.

In the improved process, heat sinks in the form of cooled metal parts are placed at the two ends of the die where the liquid material forms a meniscus. As in the current process, cold shoes are also placed along the two faces of the growing ribbon, approximately 5 mm above the height of the two end cold shoes (see Figure 2). With this modification, solidification of the silicon should start at the ends, and the point of solidification should remain below the 1-mm meniscus height limit, even at high pulling speeds. The cold shoes along the sides of the ribbon will have to be arranged to avoid overcooling of the sheet.

This work was done by Robert Richter of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 51 on the TSP Request Card.*
NPO-16692

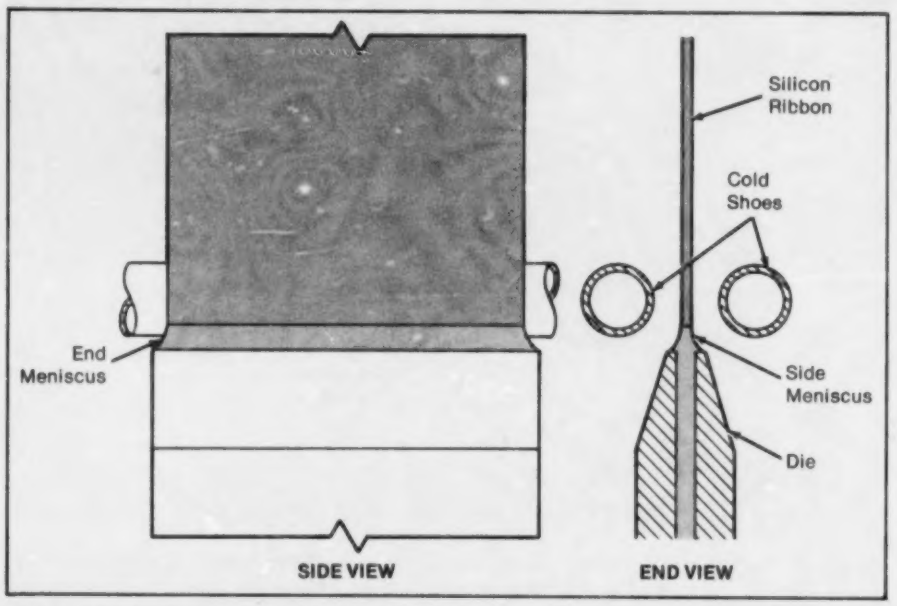


Figure 1. In the **Present Edge-Defined Film-Fed Crystal-Growth Process,** the cold shoes are placed at the sides of the emerging ribbon. The ribbon growth is determined by the maximum height (1mm) that the end menisci can reach before baking.

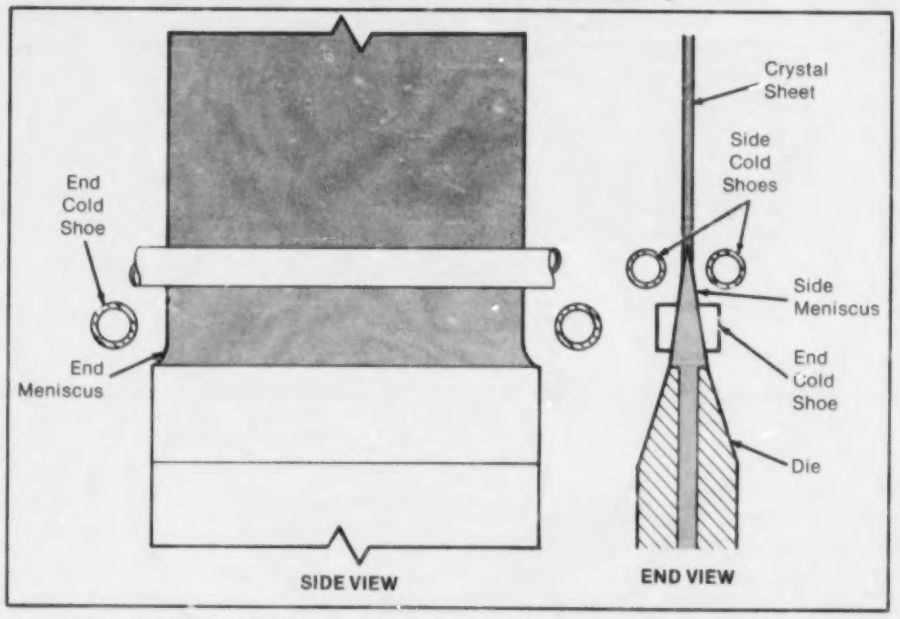


Figure 2. In the **Improved Process,** cold shoes cool the melt at the ends of the emerging sheet. Since solidification at the ends should now occur before the end menisci reach their maximum height, the ribbon could be drawn substantially faster.

Lightweight Forms for Epoxy/Aramid Ducts

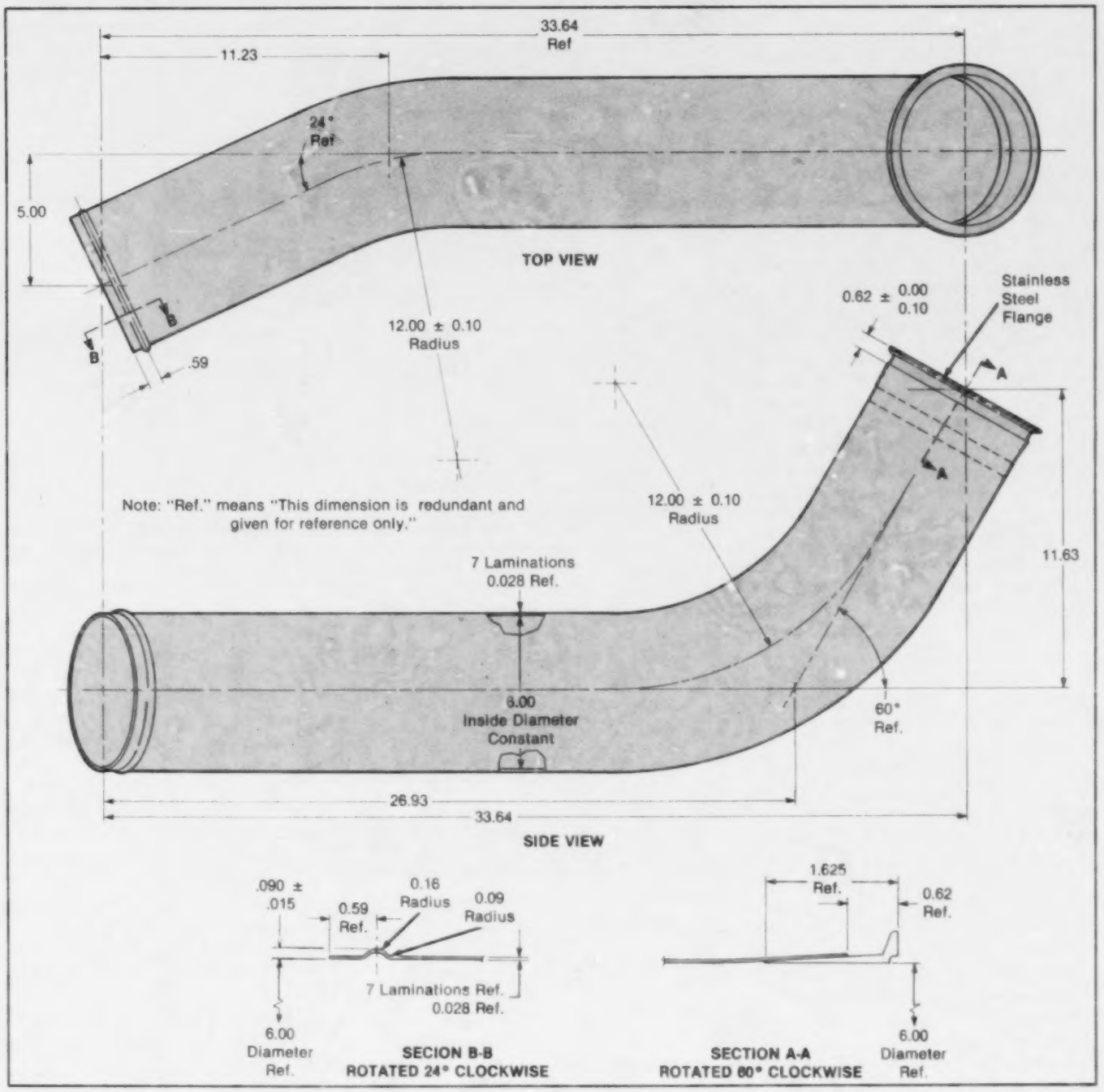
Aluminum mandrels are easy to remove.

Lyndon B. Johnson Space Center, Houston, Texas

A lightweight aluminum mandrel for shaping epoxy/aramid ducts simplifies and speeds production. Previously, the mandrel was made of plaster and, therefore, was heavier and more difficult to maneuver into and out of the curing oven than the aluminum tool. In addition, during the cure the plaster mandrel gave off moisture that tended to distort and damage the duct. Most importantly, the plaster mandrel had to be removed by slow and tedious chipping, during which the duct could easily be damaged.

In the new process, glass-reinforced epoxy/aramid cloth is wrapped on the aluminum mandrel. Stainless-steel flanges and other hardware are then fitted on the duct and held by simple tooling. The entire assembly is then placed in an oven to cure the epoxy. After curing, the assembly is placed in an alkaline bath that dissolves the aluminum mandrel in about 4 hours (compared with about 40 hours for removing the plaster form). The epoxy/aramid shell is then ready for use as a duct.

The aluminum mandrel (see figure)



A **Large-Diameter Duct** of glass-reinforced epoxy/aramid material with stainless-steel flanges was formed on an aluminum mandrel. The curvature of the duct is much more easily imparted to the aluminum mandrel than to its plaster predecessor.

has been used to make ducts of various inside diameters up to 6 in. (15.2 cm). Standard aluminum forms can be used; for example, straight tubing, Y-joints, T-joints, and other forms can be sawed and welded into a variety of shapes, ready to be wrapped. Conventional tube-bending equipment produces the requisite curves in the mandrels.

This work was done by Edward W. Mix, August N. Anderson, and Donald L. Bedford, Sr., of Rockwell International Corp. for **Johnson Space Center.** *No further documentation is available.*
MSC-20957

Low-Flammability PTFE for High-Oxygen Environments

A modified forming process removes volatile combustible materials.

Marshall Space Flight Center, Alabama

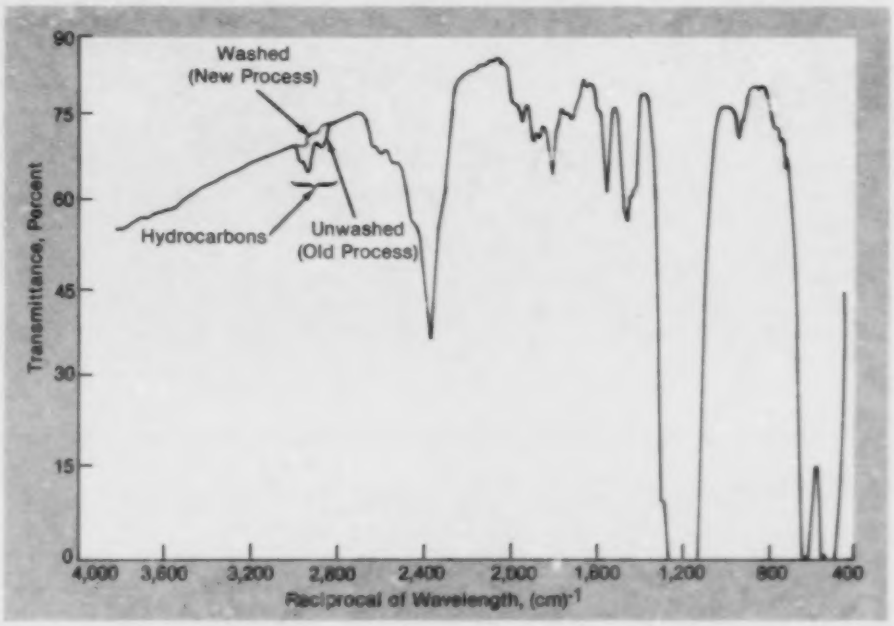
The flammability of cable-wrapping tape has been reduced by altering the tape-manufacturing process. The problem arose when liquid-oxygen-sensor cable assemblies were unable to pass a standard flammability test. Posttest infrared spectrography showed that the polytetrafluoroethylene (PTFE) tape contained small amounts of hydrocarbons.

Previously, the first step in manufacturing was the formation of billets made of PTFE powder and a hydrocarbon extrusion aid, such as naphtha or other petroleum distillates. The newly formed billets were then extruded and calendered into tape. An attempt was made to reduce flammability by sintering. Although sintering was supposed to evaporate the hydrocarbons, it actually sealed them inside the tape; therefore, the hydrocarbons were present and aided combustion during the flammability tests.

In the new manufacturing process, the tape is formed by a proprietary process of screw extrusion (instead of calendering), followed by a washing in a solvent and drying. The tape is then wrapped as before.

Spectrograms of the new tape show that it contains only a small amount of hydrocarbons (see figure). This is borne out by flammability tests, in which flames did not propagate on the tape.

PTFE formed by the new process is well suited to oxygen-rich environments. It is safe in the liquid oxygen of the Space Shuttle tank as well as in such medical uses as thin-wall shrinkable tubing in hospital test equipment, surgical instruments, and implants.



The New Process Alters the Shape of the spectrogram. The spectrogram taken after extrusion, washing, and drying shows a lower hydrocarbon content.

This work was done by E. M. Walle, B. M. Fallon, and A. T. Sheppard of Martin Marietta Corp. for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshal Space Flight Center [see page 29]. Refer to MFS-28127.

Joint for Rapid Structural Assembly

A quickly attaching joint could be used in a variety of truss structures.

Langley Research Center, Hampton, Virginia

Quickly-erecting truss structures have a variety of potential applications, from towers and geodesic-dome structures on Earth to space-station keel beams, antenna masts, and large platforms. These truss structures typically have large numbers of joints, and each joint must have the capability of quick connection at a single visit if the structure is to be erected in a reasonable time.

Other requirements of this type of joint include component simplicity, low cost, inspectability, and the ease of assembly. The joint should have positive latching that will not loosen from vibration or handling, and there should be a direct structural load path through the joint. The joint should have no external protrusion, and the parts should have no sharp edges or pointed ends to endanger the assembler. The joint should feature side-entry

attachment to facilitate the removal of a single structural strut for repair without necessitating the removal of additional pieces. It should have a preload capability to remove free play and to provide linear load-displacement response over a prescribed load range. Finally, the joint must be usable with structural members over a large range of sizes.

A new quickly-attaching side-entry joint, shown in the photograph, meets all of these requirements. A split locking ring with tapered internal sides is forced onto a matched taper that is machined on an endbell of each tube. One-half of the split ring is loosely attached to each endbell with screws or pins. When the tubes are slid together to make the joint, a wedged fit develops between the split locking rings and the endbells of the two members.

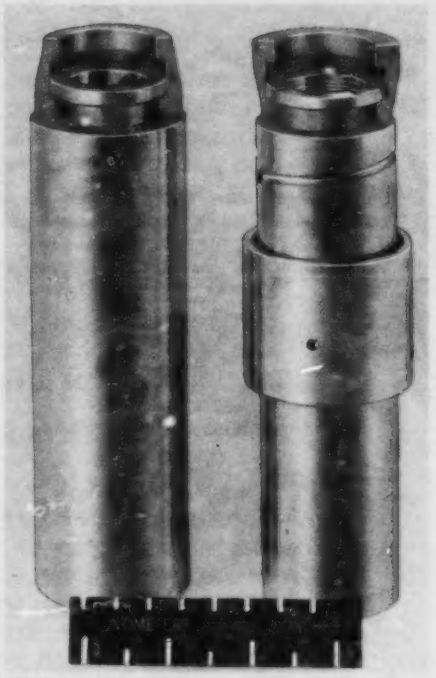
A collar attached to one member has an internal taper to match an external taper machined on the split ring. The collar is forced over the split ring, forcing the endbells together to load the joint internally. The collar is held in place by connected pins that ride in a groove machined in one of the members. The groove is machined axially along the tube to allow the rapid advancement of the collar and transitions to a spiral around the tube. Locking forces are developed when the collar and split ring are in contact.

Near the end of the groove, the pitch of the spiral goes to zero to form a circumferential groove, which locks the collar against inadvertent rotation during use. The collar may be rotated by hand or with a spanner wrench if large clamping loads are required. Release and removal are accomplished by reversing the assembly procedure.

The split ring is made in one piece and split radially after final machining. The mating tapers on the split ring and endbells are small: approximately 7° on the model shown. Tapers of this range permit high internal preloads to be obtained, yet the parts can be easily separated when the collar is released. Preliminary results from tests on the developmental model indicate that the load-displacement response is linear and that substantial preloading can be accomplished.

This work was done by Marvin D. Rhodes of **Langley Research Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13489.



Split Locking Rings and Endbells combine with the collar to enable the internal loading of the joint.

Welding and Brazing Silicon Carbide

Hot isostatic pressing and conventional furnace brazing are effective under the right conditions.

Lewis Research Center, Cleveland, Ohio

A study was performed that showed the feasibility of welding SiC using several welding and brazing techniques. One of the prime candidate structural ceramic materials for use in advanced gas-turbine and diesel engines is sintered alpha silicon carbide (SiC). The use of SiC would improve engine efficiency by allowing an increase in the operating temperature from 1,700 °F (930 °C) to about 2,450 °F (1,340 °C). Wider and more efficient utilization of SiC would be possible if means were available to weld SiC to itself with elevated-temperature properties of welded joints equivalent to those of the SiC base material.

A literature review by the Lewis Research Center revealed that fusion welding (by melting the base material) was not applicable because SiC tends to vaporize on heating, rather than melt. Since fusion welding was not applicable, feasibility studies at Lewis Research Center on solid-state welding and brazing were initiated. Results were evaluated solely by studying the microstructures of the joints.

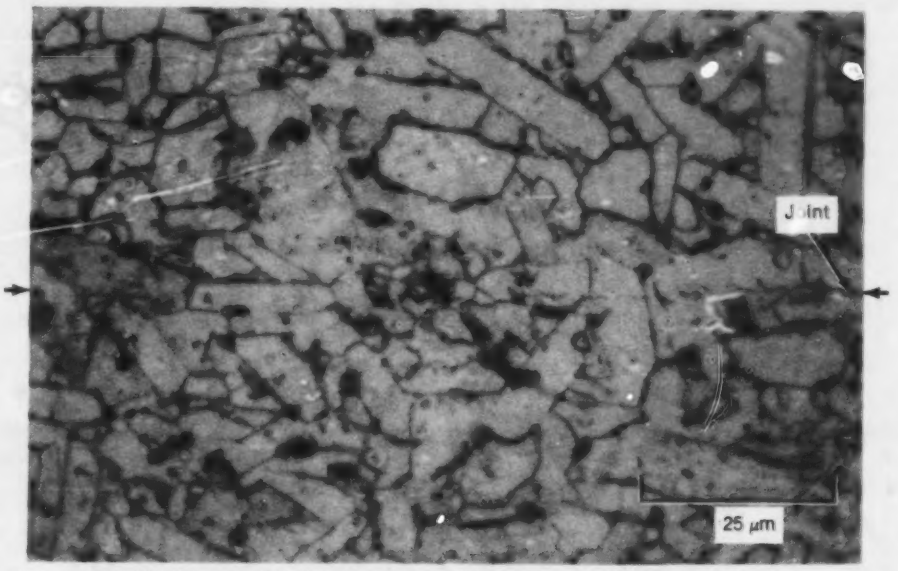


Figure 1. This **Hot Pressure Weld** in SiC was made at 1,950 °C and 138 MPa for 3 h, with 25 percent deformation. Grains have grown across the weld interface. (This sample was etched.)

It was found that SiC could be successfully hot-pressure-welded at 3,550 °F (1,950 °C) in argon (see Figure 1). Welding was possible because the SiC material flowed plastically under uniaxial pressure. Conversely, under hot-isostatic-

pressing (HIP) conditions [3,350 °F (1,950 °C), at 20 kpsi (138 MPa) for 2 h], with no plastic deformation, SiC could not be welded at all. However, HIP with AlB_{12}, B_4C, and ZrB_2 interlayers produced diffusion-welded joints successfully, and HIP with SiB_6, Al_4C_3, and $MoSi_2$ interlayers produced successfully brazed joints. The joint produced with the SiB_6 interlayer is shown at the top of Figure 2. Conventional furnace brazing techniques were used to braze SiC using a $TiSi_2$ interlayer and heating to 3,175 °F (1,746 °C) for 5 min in argon, as shown at the bottom of Figure 2.

There are now several options for welding and brazing SiC where otherwise few, if any, were available. Refinements of the solid-state welding and brazing procedures used in this study may be sufficient for some specific industrial applications; but more extensive research, including elevated-temperature strength and property determinations, would be required for most other applications.

This work was done by Thomas J. Moore of **Lewis Research Center**. *For further information, Circle 62 on the TSP Request Card.*
LEW-14251

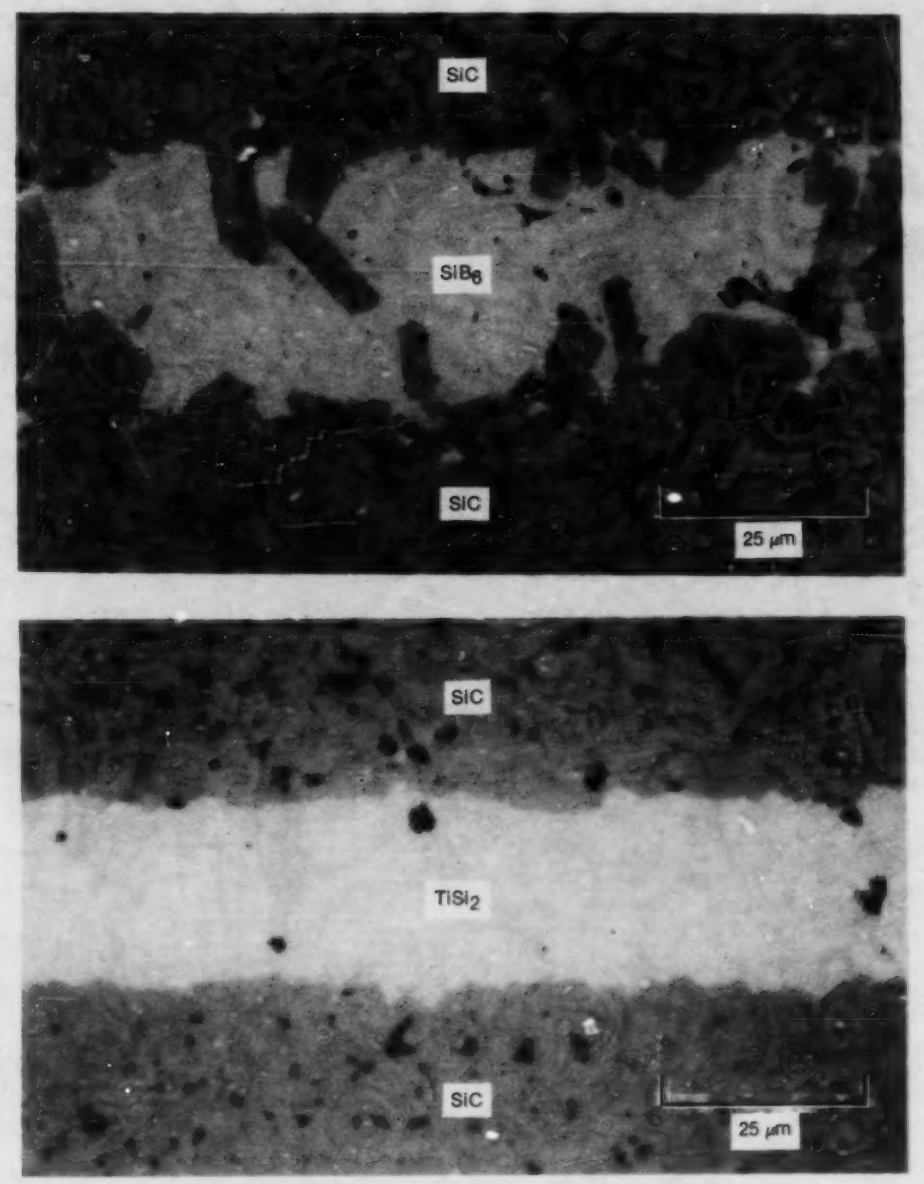


Figure 2. These **Joints in SiC Were Brazed.** In the upper sample, the SiC layers were hot isostatically pressed with an SiB_6 interlayer at 1,950 °C and 138 MPa for 2 h. SiC grains appear to have grown into the SiB_6. In the lower sample, the layers of SiC were brazed in a furnace with a $TiSi_2$ interlayer at 1,750 °C in argon for 5 min. (Both samples are unetched.)

Making a Lightweight Battery P'aque

The plaque is formed in porous plastic by electroless plating.

Lewis Research Center, Cleveland, Ohio

A lightweight nickel plaque was prepared for use as an electrode substrate for alkaline batteries, chiefly for Ni and Cd electrodes, and for possible use as electrolyte-reservoir plates for fuel cells. The usual commercial nickel plaque is made by sintering nickel powder, sometimes with binders and/or pore formers. This plaque is heavy and uses expensive powdered nickel.

The lightweight plaque is prepared by the electroless plating of a porous plastic that contains an embedded wire or expanded metal grid. The plastic may or may not be filled with a soluble pore former. If the plastic contains a soluble pore former, it is treated to remove the soluble pore former and increase the porosity. The porous plastic is then clamped into a rig that allows the plating solutions to flow through the plastic.

The essential features of the rig are as follows: Vertical walls above and below the porous plastic to allow uniform flow of the plating solutions through all parts of the plastic; a plating rig and a perforated plate made of nonplatable rigid plastic to support the porous plastic; a diffuser plate, directly beneath the porous plastic and above the perforated supporting plate, consisting of nonplatable, porous carbon such that the flow through the carbon is much more rapid than through the porous plastic (this allows more uniform flow than does a perforated plate alone), and provision for pressure or vacuum, if needed, to produce adequate flow.

Commercial electroless nickel-plating solutions prepared according to formulas in the literature may be used. Because of the high surface area of the porous plastic, the plating can be carried out at temperatures lower than those normally used. After plating, impregnation of the

plaque with active material is carried out in the usual manner.

An electrode prepared from Amerace A-40® porous plastic extracted with KOH and plated with commercial boride-based electroless nickel solutions (Allied Kelite Division), was subjected to 145 charge/discharge cycles at 100 percent depth of discharge, at current densities from 10 to 100 mA/cm^2, without loss of capacity. At a loading of 1.60 g/cm^3 void, these electrodes have a theoretical energy density of 0.23 A-h/g, compared to 0.12 A-h/g for a typical sintered electrode.

This work was done by Margaret A. Reid, Robert E. Post, and Daniel Soltis of **Lewis Research Center**. *Further information may be found in NASA TM-86861 [N84-32357/NSP], "Development of a Lightweight Nickel Electrode."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

This invention has been patented by NASA (U.S. Patent No. 4, 439, 465) ... quiries concerning nonexclusive or ex... clusive license for its commercial development should be addressed to the Patent Counsel, Lewis Research Center [see page 29]. Refer to LEW-13349.

Pressure Rig for Repetitive Casting

The equipment life is increased by improved insulation.

Langley Research Center, Hampton, Virginia

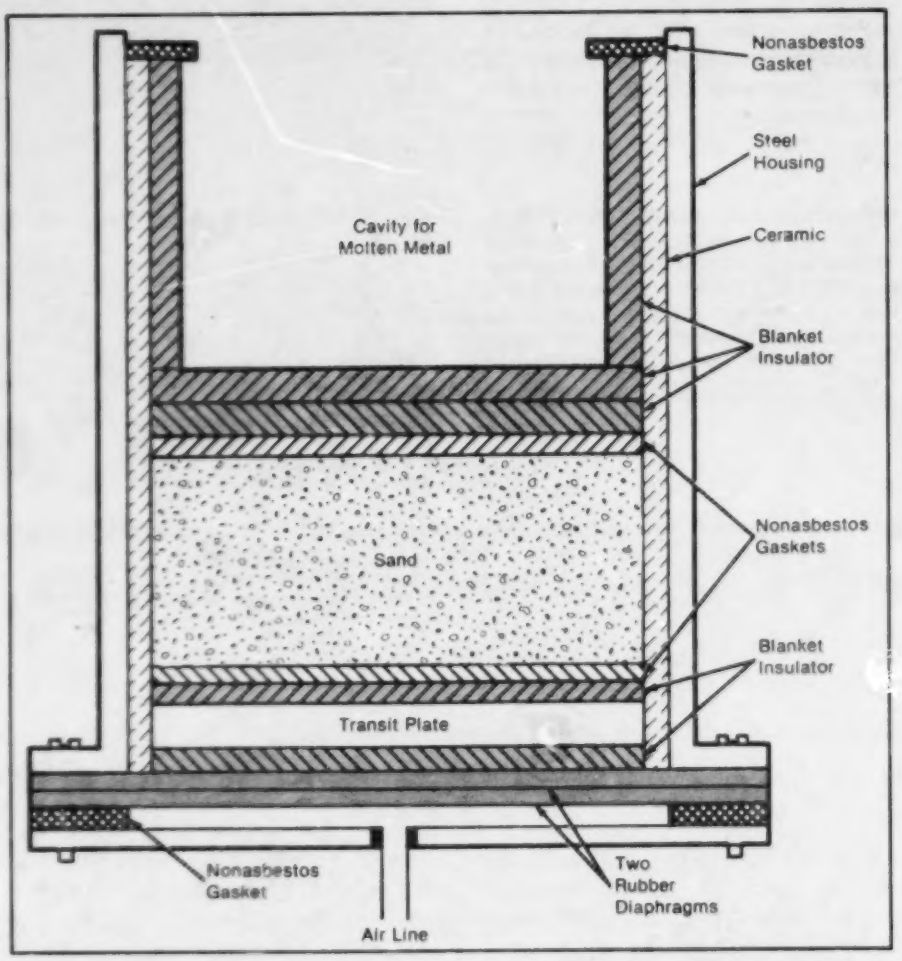
Conventional pressure rigs are designed for the casting of such low-melting-temperature alloys as aluminum or magnesium. Each casting in conventional rigs requires repreparation of the pressure-rig cavity, and the heat necessary for preparation and casting drastically decreases the life of the expanding rubber diaphragm and other components. A new design uses a commercially-available blanket-type insulator, which overcomes these problems.

The ceramic cavity (see figure) is lined with the insulating material, necessitating only a relining for subsequent use and eliminating the lengthy cavity preparations. In addition, the expandable rubber diaphragm is protected by the insulating material, thereby decreasing its vulnerability to heat damage. Finally, the hazardous asbestos gaskets in the former design are replaced by a non-asbestos material.

The new design, in use at Langley Research Center, has cut the time of preparation for casting from several days to about 1 hour. Most of this saving is due to the elimination of the lengthy heating and drying operations formerly associated with the preparation of the ceramic mold. The quality of the casting is improved because moisture in the cavity is eliminated by use of the insulating material, and a more uniform pressure is applied to the process. The life expectancy of the pressure rig is doubled by this new design, and bursting of the rubber diaphragm due to heat is minimized. Additionally, the improved heat protection has allowed the casting of brass and other alloys with higher melting temperatures in this pressure rig.

This work was done by Peter Vasquez and William R. Hutto of **Langley Research Center.** *No further documentation is available.*

LAR-13485



A Commercial Blanket Insulator protects components from heat, thereby increasing the life of the pressure rig and enabling repeated use.

Automatic-Control System for Safer Brazing

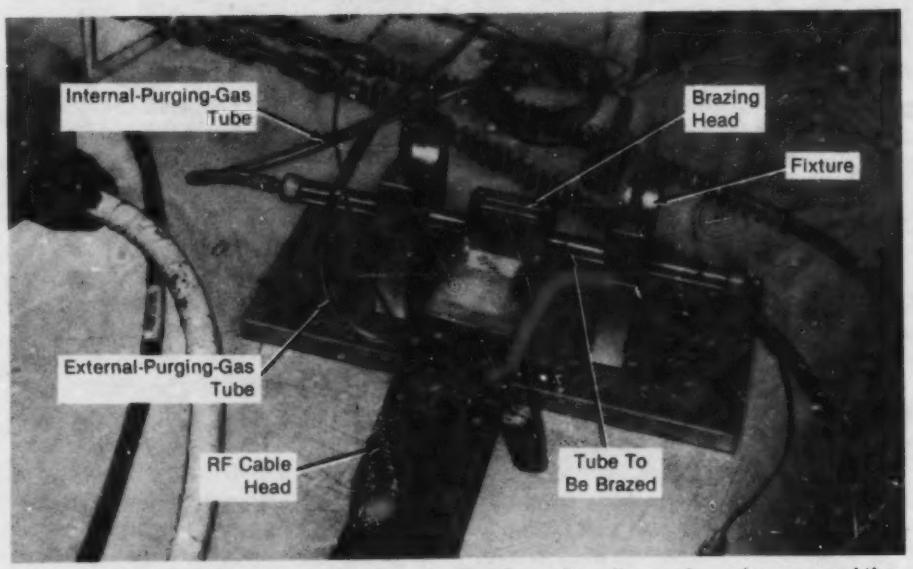
Integrated unit reduces hazards and improves product quality.

Lyndon B. Johnson Space Center, Houston, Texas

An automatic-control system for radio-frequency (RF) induction brazing of metal tubing reduces the probability of operator errors, increases safety, and ensures high-quality brazed joints. The unit combines the functions of gas control and electric-power control. It minimizes the unnecessary flow of argon gas into the work area and prevents electrical shocks from the RF terminals.

The controller will not allow power to flow from the RF generator to the brazing head unless the work has been firmly attached to the head and has thereby actuated a microswitch. A potential shock hazard is thus eliminated. In addition, the flow of argon for purging and cooling must be turned on and adjusted before brazing power can be applied. This provision ensures that power is not applied prematurely, causing damaged work or poor-quality joints. The controller automatically turns off the argon flow at the conclusion of brazing so that this potentially suffocating gas does not accumulate in confined areas.

To braze two pieces of tubing together, the operator inserts the pieces in a fixture and places the brazing head over the ends (see figure). The operator then attaches an argon-supply hose for internal purging to an end of the tubing to be brazed and a hose for external purging to the brazing head. The flow of gas to both hoses starts when the operator sets a switch on the flowmeter box. The operator adjusts the purging gas flow to 15 standard ft^3/h (120 standard cm^3/s). The internal and external flows remain on until after brazing, when the thermocouple senses that the workpiece temperature has dropped below 200 °F (93 °C). At that point, the controller turns off the flow.



Tubing Is Positioned in a fixture for brazing. The flow of cooling and purging gas and the application of RF power for induction heating are controlled automatically when the operator pushes a button to start the brazing process.

The flow of argon for cooling the brazing head enters the brazing head through a tube in the RF cable head, removes heat from the head, and exits through another tube in the cable head. The operator presets the cooling-gas supply pressure to 75 to 100 $lb/in.^2$ (500 to 700 kPa). The cooling-gas flow starts when the operator presses the "braze start" switch, continues during heating up and brazing, and stops 90 s after brazing has ended.

Before starting the brazing operation, the operator sets the temperature and power controls according to the size and type of joint. The operator then sets the timer to a maximum allowable time. (The timer is a protectively redundant power-shutoff device; normally, the power would be shut off automatically when the workpiece reached the assigned temperature, before the maximum allowable time.) When a light indicates that the work station is ready, the operator presses the "braze start" control, and brazing proceeds automatically.

This work was done by John A. Stein and Maurice A. Vanasse of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 49 on the TSP Request Card.*
MSC-20881

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Coating Circuit Boards With Silicone

Techniques appropriate to boards containing CMOS circuits are detailed.

A document presents a procedure for applying a thin conformal coating to such electronic assemblies as printed-circuit boards and wire-wrapped boards. The coating is from 1 to 7 mils (25 to 178 micrometers) thick and composed of room-temperature-vulcanizing (RTV) silicone. The document specifies the materials, equipment, spraying method, and quality requirements.

Silicone was selected as the coating material on the basis of its electrical and mechanical properties. It was evaluated, along with other materials, by sectioning, thickness measurements, microscopic examination, electrical tests, and photography.

The procedure takes into account the special needs of circuits made with complementary metal-oxide/semiconductor (CMOS) devices on circuit boards. Previously-developed conformal-coating procedures tend to induce excessive stresses in these chips

and ultimately cause failure.

Special attention is given to preventing damage by electrostatic discharge, to which CMOS circuits are especially sensitive; for example, the document notes that equipment, personnel, and assemblies should be fully grounded throughout the procedure.

The coating procedure consists of the following steps:

1. The workpiece to be coated is removed from its protective package and grounded.
2. The areas to be coated are cleaned in specified solvents.
3. The areas not to be coated are masked with tape, temporary coatings, or fixtures.
4. A primer is applied to the unmasked areas and allowed to dry at room temperature.
5. The silicone coating material is diluted with xylene and then sprayed on the workpiece.
6. The coated workpiece is cured at room temperature and humidity for a week or at 75 ±5 °C and 20 to 40 percent relative humidity for at least 16 hours.
7. The masking materials are removed.
8. The coating is inspected. Acceptance or rejection is based on such criteria as the numbers and sizes of bubbles, the thickness, adherence to the circuit board, completeness of cure, and uniformity.

This work was done by Saverio Gaudiano of **Johnson Space Center**. *To obtain a copy of the document, "Procedure for Spray Application of Thin (1-7 mils) RTV Conformal Coatings for Electronic Assemblies," Circle 8 on the TSP Request Card.*
MSC-21020

Investing in a Large Stretch Press

A press for forming large aluminum parts from plates would provide substantial economies.

A study has assessed the advantages and disadvantages of investing in a large stretch-forming press of about 5,000 ton (4.4×10^7 N) capacity per jaw. The study also developed a procurement specification for the press.

The press would be of a longitudinal-and-transverse design with a 1½-in. (3.8-cm) jaw opening and a die-table ram force of 10,000 ton (8.9×10^7 N). It would process 2219-T37 aluminum alloy plates measuring 1 by 210 by 480 in. (2.5 by 533 by 1,219 cm).

The press would be used for fabricating gores and dome segments for Space Shuttle fuel tanks. Currently, these pieces are stretch formed and chemically milled before heat treatment and final machining. Dome caps could also be made on the press — these parts are now spun-formed and machined. The pieces would be premachined (skin milled) before stretch forming, to reduce detail fabrication costs and assembly costs and eliminate the need for chemical milling.

The study found from parametric cost estimates that a large stretch press could pay for itself in fewer than 100 tank units. The major advantage of premachining and large-stretch-press forming is the saving of time through the elimination of the lengthy process currently required for chemical milling. In addition, these techniques enable the production of larger lots and thereby reduce setup costs. The study also found that increasing the size of tank gores would reduce the costs of final assembly, setup, welding, and inspection by at least 30 percent.

The study examined the question of location for the large stretch press. Water access from major producers of large aluminum plates would be essential. Without direct water access, transportation costs become prohibitive. A site in the southeastern United States is recommended on the basis of low-cost electrical power, favorable business climate and labor market, and convenience of access to suppliers.

This work was done by M. W. Choate, W. P. Nealson, G. C. Jay, and W. D. Buss of Boeing Aerospace Co. for **Marshall Space Flight Center**. *To obtain a copy of the report, "NASA/MSFC Large Stretch Press Study," Circle 79 on the TSP Request Card.*
MFS-27126

Exploiting the Vacuum of Space

Molecular-beam epitaxy and other processes could be tested with minimal contamination.

A proposed vacuum experimental facility for outer space would create vacuums higher than those available in terrestrial vacuum chambers, according to a report. The facility would minimize contamination of the work from walls and would allow the rapid removal of gases and heat generated by the experimental processes. The facility would be used for such processes as molecular-beam epitaxy (for growing semiconductor superlattices, for example), for metal/organic chemical vapor deposition, for coating mirrors and other optical components, and for ultrapurification.

The facility would include a spherical-segment shell raised on a boom above the Space Shuttle, concave side facing forward. Positioned near the apex of the shell on the convex side, the experimental apparatus would be exposed to the high vacuum of the Space Shuttle orbit but would be shielded from contaminating atmospheric molecules in the Shuttle wake. The shell would also shield the work from material outgassed by support equipment mounted on the concave side. Even most of the molecules given off by the downstream wall of the shell would not contaminate the work because this wall is not within the view of the experimental apparatus.

The remaining source of contamination, the factor that limits the attainable vacuum level, is the backscattering of atmospheric molecules by collisions with molecules outgassed from the convex wall. Backscattering would be reduced to a minimum by the choice of a low-outgassing shell material and by the use of a novel bakeout procedure in orbit. When the facility is deployed from the Shuttle, the convex side of the facility would be initially aimed in the forward direction, where the flow of rare atomic oxygen would help to remove traces of hydrocarbons that might later outgas. After this exposure, the concave side of the shell would be pointed toward the Sun. In that position, the polished metal surface would heat up; in effect, it would be baked out by the Sun to reduce outgassing further. At the end of the bakeout period, the shell would be turned to the forward-concave orientation. These cleaning and baking provisions should enable the attainment of vacuums of 10^{-12} to 10^{-14} torr (about 10^{-10} to 10^{-12} N/m^2) in the experimental apparatus.

The device to be processed would have to be degreased and cleaned on Earth. It would be shrouded against contamination during launch and deployment. The finished vacuum-processed work would be stored in protective containers and returned to Earth on the Space Shuttle. The concept can readily be adapted to service on the Space Station as well as on the Space Shuttle. It will then be more economical, since the facility will not have to be transported back and forth between Earth and orbit.

An important feature of the facility not shared by ordinary vacuum

chambers is that emissions from a process would be less able to contaminate it, thereby making it unsuitable for use with other materials. For example, although experimenters are strongly interested in building mixed lattices of groups III/V and II/VI elements by molecular-beam epitaxy, they are reluctant to risk contaminating expensive vacuum chambers, dedicated to III/V work with II/VI materials, and vice versa. With the new ultra-vacuum device, however, most of the emissions would disappear into space.

This work was done by Robert J. Naumann of **Marshall Space Flight Center**. *To obtain a copy of the report, "Space Ultra-Vacuum Facility," Circle 40 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28139.

Physics of Fusion Welding

The applicabilities and limitations of three techniques are analyzed.

A NASA technical memorandum discusses the physics of electron-beam, gas/tungsten-arc, and laser-beam welding. From a comparison of the capabilities and limitations of each technique with regard to various welding conditions and materials, it is possible to develop criteria for selecting the best welding technique in a specific application.

All three techniques are classified as fusion welding; that is, a small volume of the workpiece (the weld puddle) is melted by an intense heat source. The heat source is moved along the seam, leaving in its wake solid metal that joins the seam edges together.

Gas/tungsten-arc welding is usually done manually, especially on parts that are too complicated for automated welding. Electron-beam welding is not suitable for manual operations because it must be done in a vacuum. Both electron-beam and laser welding are best done by robots because these processes are difficult to control safely by hand.

The broad, rounded puddle usually produced in gas/tungsten-arc welding must either melt a lot of metal with consequent damage to the workpiece and high power consumption, or else its penetration must be limited. A weld is typically built up in multiple passes, each contributing a small fraction of the total weld cross section. The use of many passes raises the cost and increases the incidence of defects.

Both electron-beam and laser welding are capable of greater penetration with less damage to the surrounding material. Both are capable of "keyholing"; that is, forming a vapor cavity that pushes the molten metal aside and aids the penetration of the beam. An electron beam can readily penetrate the vapor in the keyhole, while a laser beam is defocused and stopped by a plume of ionized gas issuing from the keyhole. In cases in which either technique might be used, a laser may be preferable if there is a risk of overpenetration.

Both gas/tungsten-arc and electron-beam welding are sensitive to magnetic fields. Because a ferromagnetic workpiece can become ionized by welding currents, it may cause the welding beam to wander. When dissimilar metals are welded, thermoelectric currents are generated and these, too, may cause erratic behavior of the beam. The effect is especially severe if one of the dissimilar metals is ferromagnetic.

The three techniques differ somewhat with regard to internal and external defects. The straighter, narrower holes produced by keyholing in electron-beam and laser welding result in less thermal distortion of the workpiece than is observed in gas/tungsten-arc welding. Porosity is more likely to occur in gas/tungsten-arc welding than in the other types. Most of the common external defects in all three cases can be eliminated with appropriate automation.

The following is an example of the selection of a welding technique: It is necessary to have the deep penetration and relatively low distortion afforded by keyholing. This excludes gas/tungsten-arc welding. It is also necessary to operate in air, and magnetic fields may be present. This excludes the use of an electron beam. In this case, only laser-beam welding is acceptable.

This work was done by A. C. Nunes, Jr., of **Marshall Space Flight Center**. *Further information may be found in NASA TM-86503 [N86-11473/NSP], "A Comparison of the Physics of Gas Tungsten Arc Welding (GTAW), Electron Beam Welding (EBW), and Laser Beam Welding (LBW)."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 41 on the TSP Request Card.
MFS-27138

Properties of VPPA-Welded 2219-T87 Aluminum

Metallurgical properties and effects of welding are described.

A report describes an investigation of the welding of 2219-T87 aluminum alloy by the variable-polarity plasma-arc (VPPA) process. The purposes of the research were to determine the highest strength attainable with this alloy and process and to estimate the changes in weld properties caused by variations of process controls.

Alloy 2219 is strong and heat treatable and retains its structural integrity up to 600 °F (316 °C). This is the principal structural alloy of the Space Shuttle external tank. The VPPA process offers many advantages and is now replacing the tungsten/inert-gas process that was used initially. In over 24,000 in. (610 m) of welds on the tank, there has been no internal defect requiring manual repair.

In the VPPA process, the current, voltage, and polarity are changed with time in a controlled manner. The primary advantage is in the 4-ms reverse-polarity portion of the welding cycle, during which argon ions bombard the workpiece and remove the oxide layer. During the 19-ms forward-polarity interval, the alloy is heated by the impingement of hot electrons. The plasma (of which the argon ions and the electrons are principal components) acts as a constraint that reduces the sensitivity of the weld to the distance between the welding torch and the workpiece.

VPPA welding can be done in the "keyhole" mode, in which the weld penetrates through the total thickness of the workpiece. By the appropriate control of the electrical current and the gas-flow rate, the plasma pressure can be increased to form a stable keyhole that moves with the weld. The hole is filled as the weld moves on. The liquid layer in the keyhole is so thin that gases released during freezing are swept away rather than being entrapped to form porosity in the final joint.

In the investigation, welded and unwelded specimens of the alloy were subjected to tensile tests and examinations by scanning-electron microscopy. Microchemical analysis was also performed in the scanning electron microscope by examination of the X-ray spectra produced by bombardment of the sample surfaces with 5-keV electrons.

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Circle Reader Action No. 328

The strength of welded panel was found to depend on a number of interacting factors. The composition of the base metal and modifications of this composition by the filler metal govern the dimensions of microstructural features, which in turn influence the weld strength. Other factors that affect the microstructure and strength include the heating and cooling rates, preheating, and the angle between the weld and the direction in which the alloy plate was rolled during manufacture.

Interdendritic particles in the fusion zone contribute to void formation, which controls the ultimate tensile strength. A variation of 150 μm in size was found to correspond to a variation of 10 kpsi (69MPa) in ultimate tensile strength. All fracture surfaces were of the dimple-rupture type, with fracture beginning in the fusion zone. Welds were found to be stronger when aligned with the rolling direction. The application of water-cooled blocks along the weld track produced a small increase in the strength and toughness of the weld.

This work was done by W.A. Wilson of **Marshall Space Flight Center** *Wartan A. Jemian of Auburn University. To obtain a copy of the report, "The Strength and Characteristics of VPPA Welded 2219-T87 Aluminum Alloy," Circle 50 on the TSP Request Card.*
MFS-27105

Deployable Construction Platform

A structure folds compactly for transportation but opens into a large work and storage area.

A report describes a concept for a deployable platform for the construction of large structures. Developed for use on a space station, the concept includes folding structural parts that may be adaptable to portable or field-assembled terrestrial structures.

The platform would be a central location for building structures, storing equipment and parts, and servicing and checking out space vehicles. The platform would provide electrical power, lighting, and tools.

The deployed platform would consist of a truss structure attached to a transfer tunnel at a docking port on the space station. A pair of rails, supported by truss members, would brace large modules delivered to the space station. Compartments installed within truss members would store such small items as tools, holddown mechanisms, and auxiliary lights. A lightweight hangar would protect astronauts while they work on the platform; it would allow them to move about untethered on the platform and would contain small objects that happened to float free.

According to current plans, the platform floor area would measure 18 by 28 m. The truss would be composed of graphite /epoxy tubes typically about 2 m long.

Knee joints in the centers of the surface struts and pin joints and the clustered ends of the struts allow the truss to fold compactly for transportation to orbit. The entire truss would fold into a package measuring 2.72 by 1.75 by 2.24 m.

This work was done by Richard M. Gates and Kenneth P. Hernley of Boeing Aerospace Co. **Marshall Space Flight Center.** *To obtain a copy of the report, "Deployable Construction Platform," Circle 58 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center (see page 29). Refer to MFS-28117.

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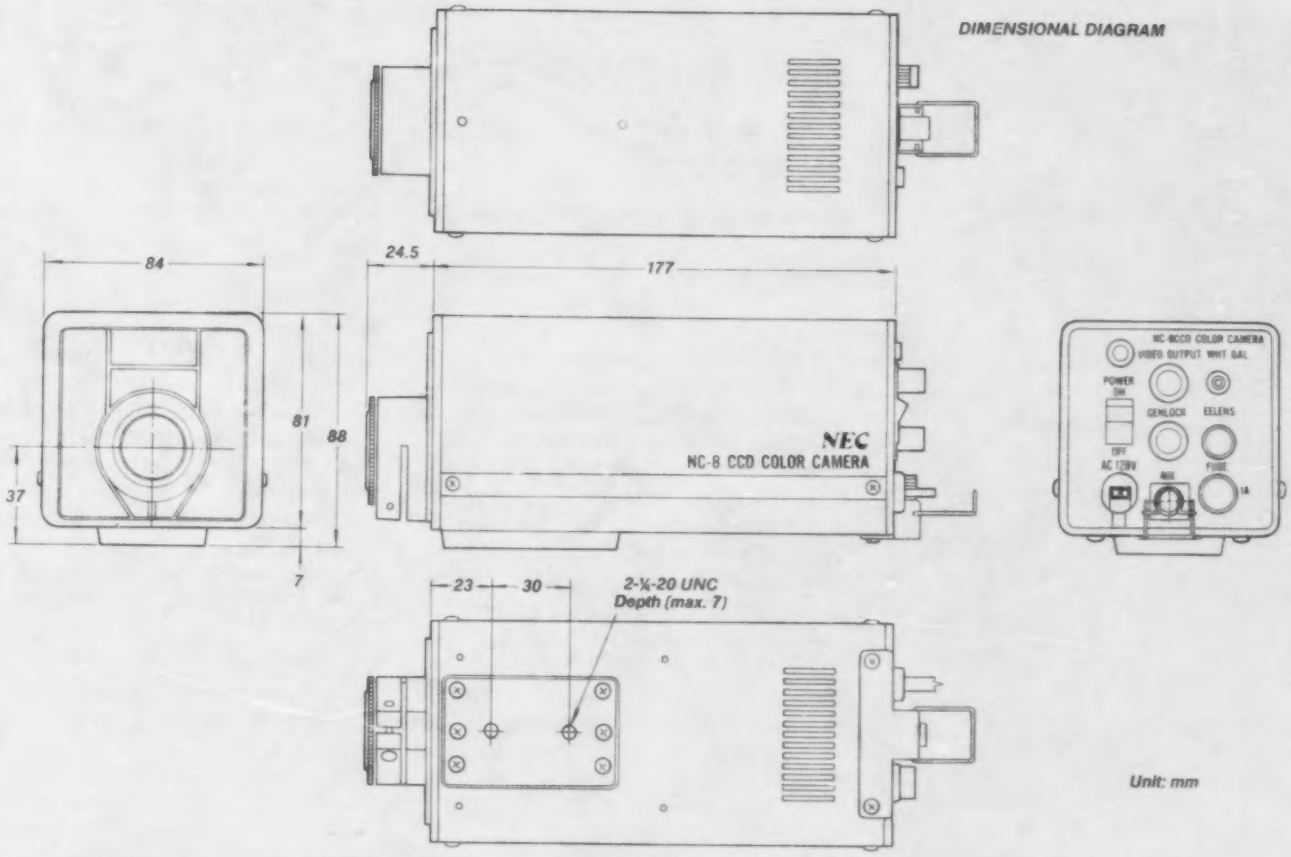

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Circle Reader Action No. 369

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Function-Keypad Template Filer

Each page of this filer shows various keypad designations corresponding to a variety of software packages.

NASA's Jet Propulsion Laboratory, Pasadena, California

Microcomputer operators using a variety of software packages can be assisted by a simple filer that illustrates various keyboard functions corresponding to different software packages. Keyboard functions can change, depending on the selected software. The filer has a set of templates showing keyboard functions for various software packages. The templates can be set up quickly as desktop references to the key functions.

Usually, overlay templates have been placed over the function keys, indicating only their function with a particular software package. If each template corresponds to one software package, the user frequently has to swap one template for another (since templates do not stack easily on the keyboard), losing time in locating the desired template. Alternatively, the same template can indicate different sets of functions for each key. This can be confusing. Moreover, if eyestrain is to be avoided, the print on the templates has to be sufficiently large so that no more than four or five different sets of functions could be indicated on a single template.

These difficulties are avoided by the function-keypad template filer. The filer has the various templates bound together so that they can be indexed easily and stood up for ready viewing. Template filers are made of inexpensive materials. Templates of various manufacturers can be added in pages appropriately die cut to receive them.

The template filer comprises several rigid sheets of material arranged in hinged or jointed binding; for example, a spiral-ring binding (Figure 1). The filer rests on a base page. The page next to the base page is scored to be folded into a triangular support for the assembly of

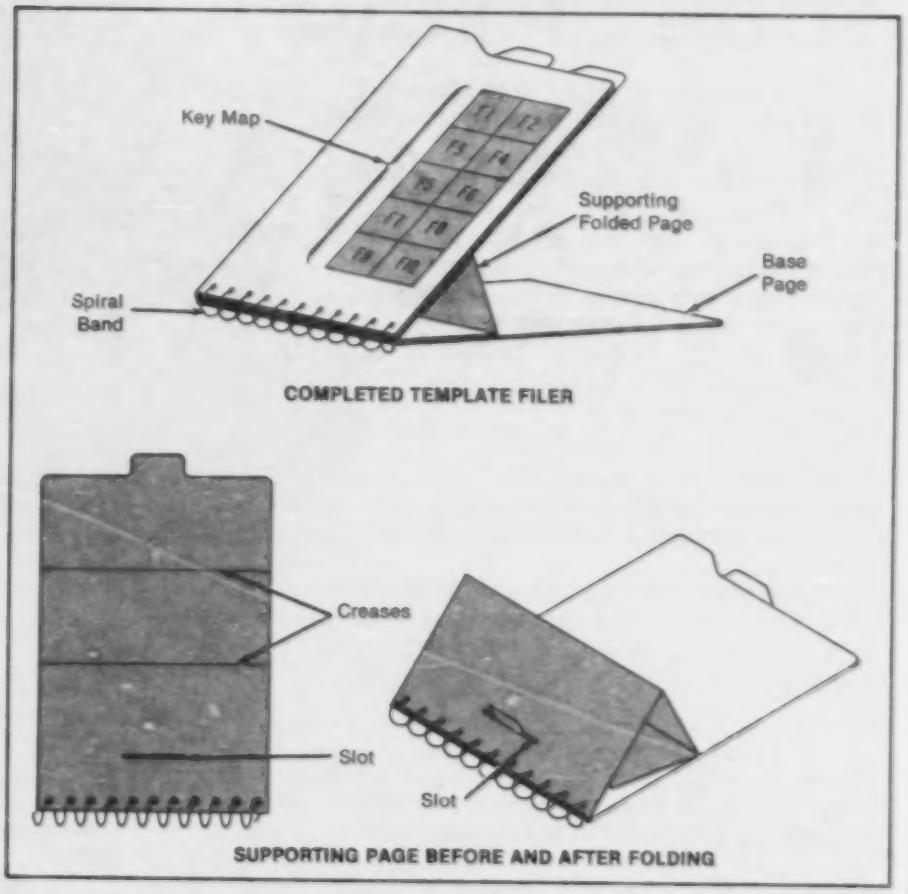

Figure 1. **The Inner Pages of the Function-Keypad Template Filer** are maintained at a convenient viewing angle by a triangular support constructed from the page above the base page.

inner pages. A tab and tab slot are provided to secure the triangular base.

As shown in Figure 2, some of the inner pages are printed to represent a particular key map, while slotted pages are used to hold the plastic templates that are popular in software applications. Index tabs at the tops of the pages allow the function-keypad templates to be located quickly.

This work was done by Paul A. Headley of Caltech **NASA's Jet Propulsion Laboratory**. *For further information, Circle 77 on the TSP Request Card.*
NPO-16676

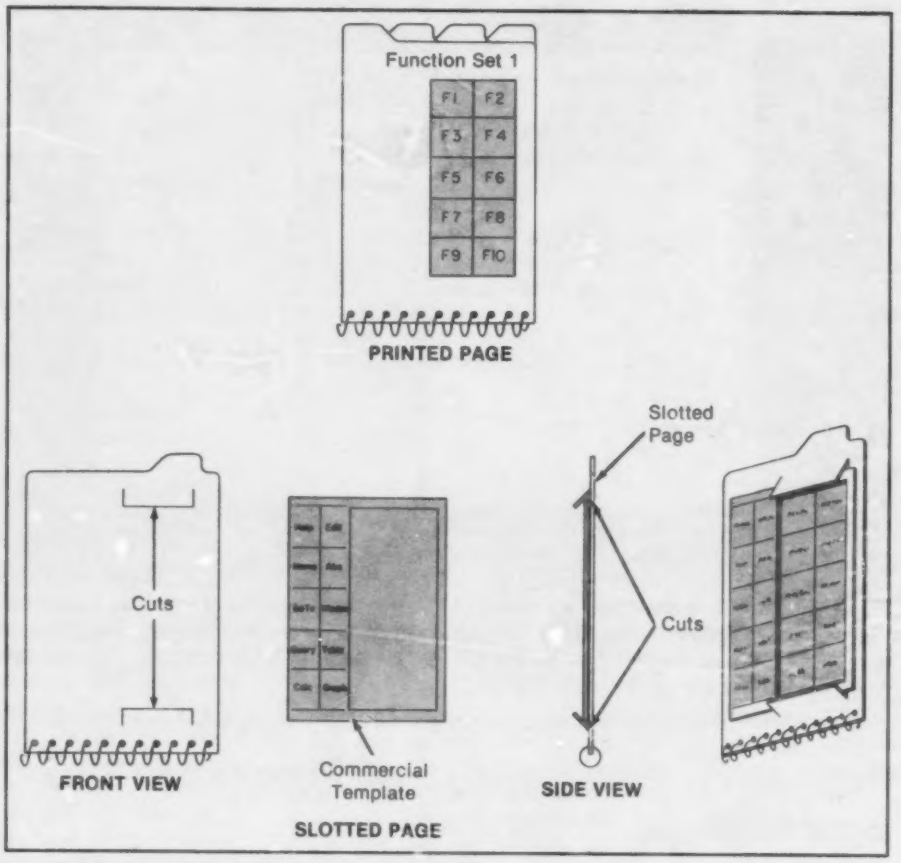

Figure 2. **Printed Inner Pages** represent a particular keyboard. Alternatively, slotted pages hold the commercial templates indicating the key functions.

Solving Nonlinear Coupled Differential Equations

A harmonic balance method gives useful results fairly easily.

Lewis Research Center, Cleveland, Ohio

A harmonic balance method has been developed to obtain approximate steady-state solutions for nonlinear coupled ordinary differential equations. Such equations arise, for example, in determining the motion of an unbalanced, rigid disk in a shaft system. Although the nonlinear terms are commonly neglected in rotordynamic calculations, order-of-magnitude analysis indicates that they are significant in geared shaft systems.

Up to now, suitable techniques have not been available for solving the complete nonlinear equations. However, the method of harmonic balance is a suitable solution technique. Moreover, the method is usable with transfer matrices, which are commonly used to analyze shaft systems. The solution to the nonlinear equation, with a periodic forcing function, is represented as the sum of a series similar to a Fourier series but with the form of the terms suggested by the equation itself. As an example, if one considers the equation for the two-degree-of-freedom spring-mass pendulum system shown in Figure 1

$$\ddot{r} - r\dot{\theta}^2 + C_\theta/m\dot{r} - g(1 - \tfrac{1}{2}\theta^2) + k/m(r - l) = 0$$

$$r^2\ddot{\theta} + 2r\dot{r}\dot{\theta} + (C_\theta/m)\dot{\theta} + gr(\theta - \theta^3/6) = T_0/m \sin(\omega t)$$

where a two-term Taylor series has been substituted for the usual trigonometric terms on the left sides of the equations.

Examination of the equations suggests the following form of solution

$$\theta(t) = \theta_{11} \sin(\omega t) + \theta_{12} \cos(\omega t)$$

$$r(t) = r_0 + r_{21} \sin(2\omega t) + r_{22} \cos(2\omega t)$$

These assumed solutions are substituted into the differential equations. By ignoring harmonic terms not in the assumed solution and applying the principle of harmonic balance, one produces five nonlinear polynominals in the five unknowns r_0, r_{21}, r_{22}, θ_{11}, and θ_{12}. The nonlinear algebraic equations thus produced are solved by an iterative method.

Figure 2 shows the θ response obtained for an example problem, with the

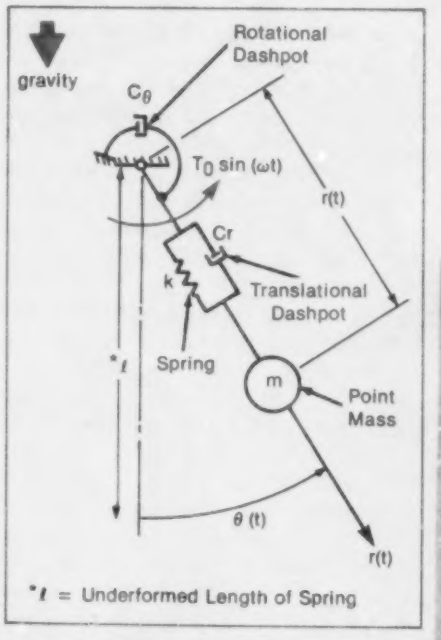

Figure 1. A **Pendulum** includes a point mass suspended on a spring. Both the spring flexing and pendulum rotation are damped by dashpots.

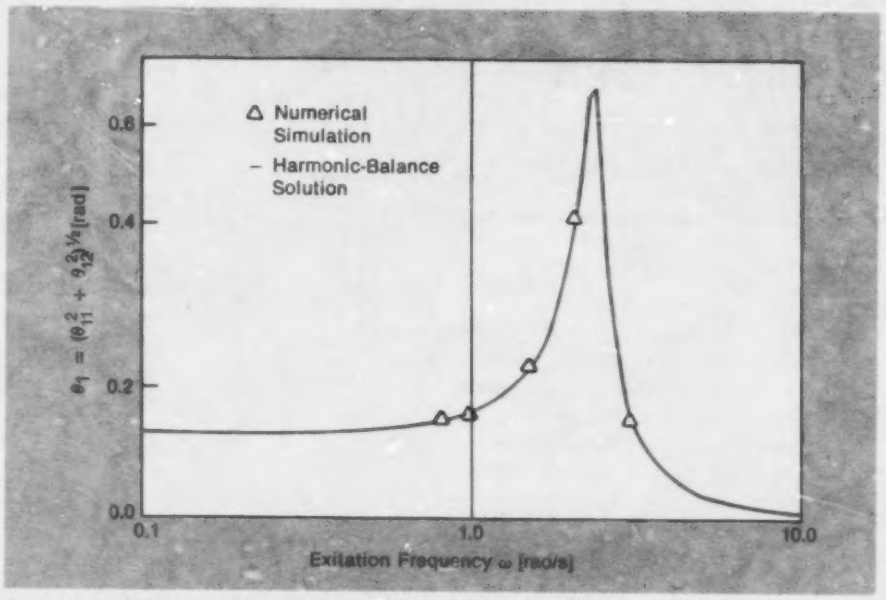

Figure 2. **Solutions to the Equations of Motion** for the pendulum of Figure 1 were obtained by the harmonic-balance method and numerically from the original differential equations. These are steady-state solutions for m = 10 kg, k = 100 N/m, C_R = 10 N·m/s, C_g = 10 N·m·s, T_0 = 25 N·m, l = 1 m, and g = 9.81 m/s^2.

approximate solution compared to a precise numerical solution of the original differential equations. The system parameters were such that the response was fairly large. In light of the large nonlinearity in the differential equations, the agreement between the harmonic-balance and numerical solutions is considered good. The solution precision could be improved further, if necessary, by using higher-order harmonic terms in the assumed solution form.

This work was done by L. D. Mitchell and J. W. David of the Virginia Polytechnic Institute for **Lewis Research Center**. *For further information, Circle 14 on the TSP Request Card.*
LEW-14165

Economic Comparison of Processes Using Spreadsheet Programs

An inexpensive approach can aid plant-design decisions.

NASA's Jet Propulsion Laboratory, Pasadena, California

Commercially available electronic spreadsheet programs can aid the economic comparison of different processes for producing a particular end product. This can facilitate plant-design decisions without requiring large expenditures for powerful mainframe compuiers.

To estimate plant performance, data for process feeds, yields, and utility requirements are first entered in the spreadsheet "baseline" (first) column (see table). Performance parameters can then be calculated and displayed in the second column. Using the performance parameters, the process analyzer can quickly compare the baseline parameters and adjust the performance parameters as desired.

The adjusted performance parameters (placed in the third spreadsheet column) and mathematical functions that describe the interactions of unit operations in a simplified block flow diagram of the plant then yield adjusted baseline values, which are displayed in the fourth column. Repeating these procedures for the different plants allows their adjusted baseline performance data to be compared.

For each plant, stored, adjusted baseline performance data enable the estimation and tabular display of costs for each plant component and for the entire plant. After the "adjusted" baseline performance is calculated, the cost of each plant component is estimated by use of calculated values stored in the spreadsheet cells. A cost-estimate template can be made from unit costs and scaling exponents. Then installed-unit costs are scaled according to the following:

A	B	C	D	E	F	G	H	I	K	L	M
1											
2				PLANT	DESIGN	A					
3											
4							Adjusted				
5		BASELINE		Performance			Performance			Adjusted	
6				Parameter			Parameter			Baseline	
7											
8											
9	Coal feed (TPD)	4607.0								4746.5	
10	Coal feed (MMBtu/hr)	4697.2								4839.4	
11	Coal feed (MW)	1376.3								1417.9	
12	Pipeline gas feed (MMBtu/hr)	36.9								0.0	
13	Oxygen (or air) feed (TPD)	3860.0		0.838		0.813				3859.5	
14											
15	Gasifier gas (MMBtu/hr)	3630.0		0.773		0.750				3629.6	
16	Gas as fuel to cleanup (MMBtu/hr)	36.9		0.008		0.005				24.2	
17	Treated gas (MMBtu/hr)	3593.1								3605.4	
18											
19	POWER GENERATORS:										
20											

Process Feeds, Yields, and Power Requirements of a coal-gasifier/fuel-cell powerplant are summarized from design data and displayed on a spreadsheet, a small section of which is shown here. These input data are used for technical and economic performance estimates.

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X ☐ Communications
C ☐ Chemicals
M ☐ Materials
P ☐ Power & Energy
B ☐ Bio/Medical
N ☐ Nuclear
T ☐ Transportation
G ☐ Government
D ☐ Defense
V ☐ Oceanography
Q ☐ Industrial Equipment
R ☐ Research Lab
U ☐ University
K ☐ Consultant
L ☐ Library
F ☐ Financial
Z ☐ Other (specify): _____

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76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
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$$\text{installed cost of unit B} = \text{installed cost of unit A} \times \left(\frac{\text{capacity of unit B}}{\text{capacity of unit A}}\right)^{n}$$

where n is a scaling exponent between 0 and 1.

From plant costs and the appropriate economic assumptions, the required product selling price can be estimated and displayed. The spreadsheet approach also allows the quantification of the uncertainties in the estimates of performance and cost, and for the pictorial presentation of the results of sensitivity analyses and comparisons, by use of the graphic routines built into the spreadsheet software package.

This work was done by Joseph F. Ferrall, Alfred W. Pappano, and Charles N. Jennings of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 46 on the TSP Request Card.*
NPO-16660

Computer Program To Transliterate Into Arabic

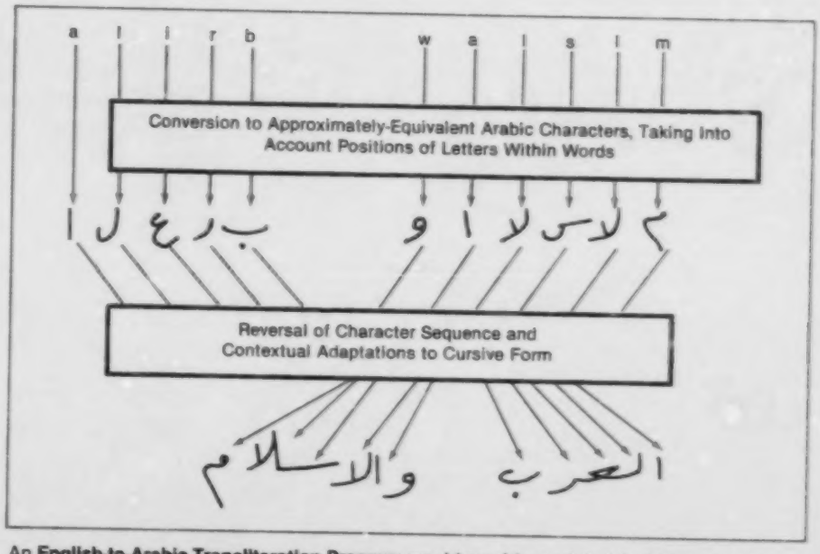
A computer would be used as an Arabic typewriter.

John F. Kennedy Space Center, Florida

A conceptual program for the TRS-80, Model 12 (or equivalent) computer would transliterate from the English letters of the computer keyboard to Arabic characters in the output of the associated printer. The program would automatically change the character sequence from the left-to-right of English to the right-to-left of Arabic. It would be easy to use and involve minimal shifting. (Current Arabic typewriters require much shifting because almost every letter has four forms: one used at the beginning, one in the middle, one at the end of a word, and one standing alone.)

The figure gives an example of how the program would function, using the Arabic phrase for "the Arabs and the Moslems." Of course, a dot-matrix printer would have to be used in the absence of a printing head with Arabic characters. Since graphics are used to create the cursive characters, the user can virtually create any "font" desired by making alterations in the "basic" program.

The program would leave 16 keys unused with the shift. These could be used for Arabic punctuations that lack, or look different from, English equivalents. These keys might also be used for commands if a word-processing program is developed.


a l l r b w a l s l m
Conversion to Approximately-Equivalent Arabic Characters, Taking Into Account Positions of Letters Within Words
Reversal of Character Sequence and Contextual Adaptations to Cursive Form

An **English-to-Arabic Transliteration Program** would provide a printed Arabic output from a keyed-in English transliteration.

This work was done by Emile Stephan of **Kennedy Space Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11342.

Larger Convergence Zones for Newton's Method

An iterative technique applies over a wider range of initial guesses.

Marshall Space Flight Center, Alabama

A new theorem describes the convergence zone of Newton's iterative method for finding the zeros of a real function. A previous theorem, called the contraction mapping theorem, was overly restrictive in that it guaranteed convergence over only a portion of the new, larger convergence zone.

In using Newton's method, one makes an initial guess, x_0, of the solution to the equation $f(x) = 0$. If x_0 lies in the convergence zone, then the first iterate, $x_1 = x_0 - f(x_0)/f'(x_0)$ lies closer to the solution than does x_0. Similarly, one can calculate the second iterate, $x_2 = x_1 - f(x_1)/f'(x_1)$. If this process is repeated many times, the nth iterate approaches the exact solution, x_z.

The new theorem involves two points, x_p and x_p^*, called the primary conjugate points. If the exact solution lies between

these points ($x_p < x_z < x_p^*$) and there are no other conjugate points in this interval, then according to the theorem, subsequent iterations will converge upon the exact solution if the initial guess lies in the interval.

Newton's method diverges (or at least fails to converge properly) for x_0 outside the convergence zone. If x_0 lies at one of the primary conjugate points, the method neither converges nor diverges; instead, x_1 is the other conjugate point, and x_2 is the initial guess, x_0. Thus, the subsequent iterations oscillate between the primary conjugate points if x_0 is one of these points.

The associated function, A(x), is useful in finding the conjugate points and analyzing the convergence properties of f(x). It is defined as the difference between the second iterate and the initial guess

$$A(x_0) = x_2 - x_0 = [f(x_0)f'(x_0) + f(x_1)f'(x_1)]$$

Since $x_2 = x_0$ for an initial guess at x_p or x_p^*, and since all iterations give x_z for an initial guess at x_z

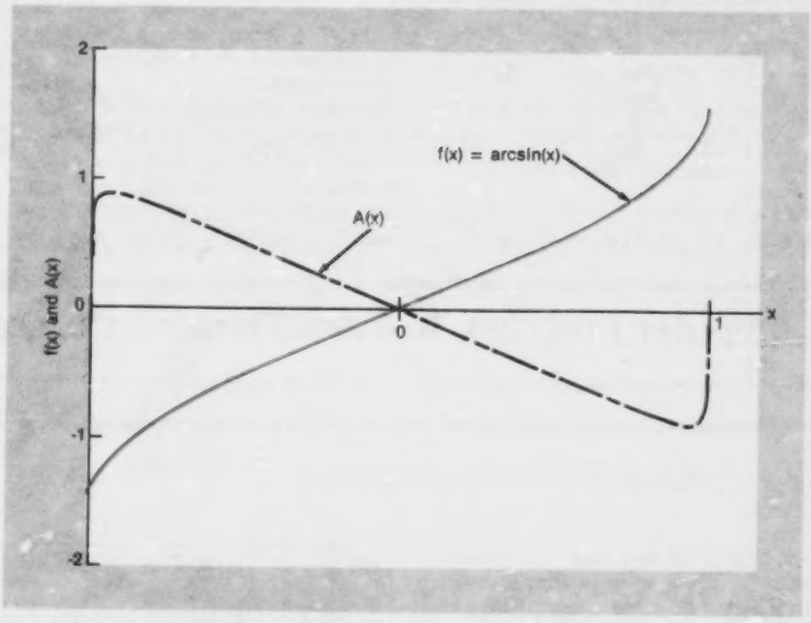
$$A(x_p) = A(x_p^*) = A(x_z) = 0$$

Another useful property is that $A'(x_z) = -1$ so that A(x) must be positive in the part of the convergence zone below x_z and negative in the part above x_z. These properties are illustrated in the figure, which shows f(x) and A(x) for the inverse sine of x.

The proof of the convergence theory depends on the following restrictive assumptions:

- $f(x_0)$, $f(x_1)$, and their first and second derivatives must be continuous on an interval that includes the primary conjugate points.
- $f(x_p)f''(x_p)$, $f(x_p^*)f''(x_p^*)$, and $f''(x_p)f''(x_p^*)$ must all be negative.
- $f'(x_0)$ and $f'(x_1)$ must be nonzero between the primary conjugate points.

These assumptions may be overly restrictive; future research on A(x) may result in a more general convergence criterion.



The Function and Associated Function for the arcsin(x) illustrate the convergence of Newton's method in the interval between $x_p = -1$ and $x_p^* = 1$.

This work was done by C. Warren Campbell of **Marshall Space Flight Center**. *Further information may be found in NASA Technical Paper 2489 [N85-28656/NSP]. "Convergence of Newton's Method for a Single Real Equation."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 17 on the TSP Request Card.
MFS-27124

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Five-Parameter Bivariate Probability Distribution

Theory and applications are discussed.

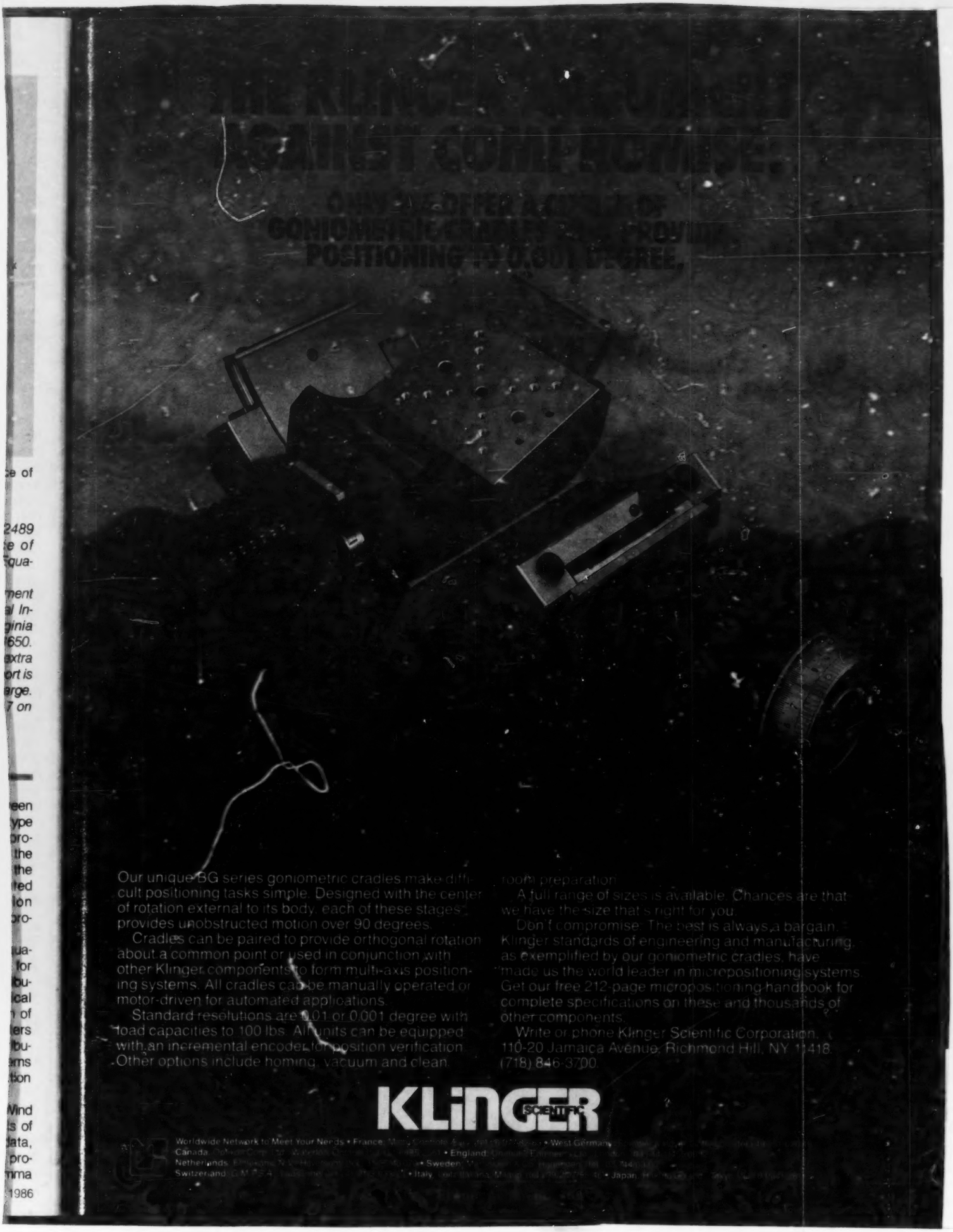
A NASA technical memorandum presents four papers about the five-parameter bivariate gamma class of probability distributions. With some overlap of subject matter, the papers address different aspects of the theory of these distributions and the use of them in forming statistical models of such phenomena as wind gusts.

The first paper, "A Note on the Ratio of Positively Correlated Gamma Variates," derives the density and the distribution functions for the ratio of positively-correlated gamma variates using a modification of Jensen's bivariate gamma distribution. The expressions for the moments differ from those given by some previous authors, but all the expressions are identical when the variates are uncorrelated. One advantage of this representation lies in the ability to compute the cumulative distribution function of the ratio. In addition, this function has potential for use in testing for the equality of shape parameters in a particular family of bivariate gamma distribution functions.

The second paper, "A Method for Determining If Unequal Shape Parameters Are Necessary in a Bivariate Gamma Distribution," describes a procedure to help an experimentalist in deciding between four and five parameters in a Jensen-type bivariate gamma distribution. The procedure is based on the properties of the cumulative distribution function for the ratio of correlated gamma-distributed variates. A preliminary evaluation showed promise, even though the procedure is not universally applicable.

The third paper, "A Differential Equations Approach to the Modal Location for a Family of Bivariate Gamma Distributions," gives analytical and numerical methods for determining the location of the mode as a function of the parameters of a class of bivariate gamma distributions. The authors derive new theorems and use them to calculate modal-location functions in numerical examples.

The fourth paper, "Analysis of Wind Gust Data," summarizes the analysis of wind-gust magnitude and length data, using mathematical and statistical procedures developed for bivariate gamma



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distributions. The data were partitioned according to altitude and analyzed by univariate and multivariate techniques. Neither the normal nor the bivariate gamma class of distributions was found acceptable at all altitudes for all wind components. However, both classes may provide acceptable results for defining constraints in such problems as designing aircraft and spacecraft to withstand large wind-gust loads.

This work was done by J. D. Tubbs, D. W. Brewer, and Orvel W. Smith of **Marshall Space Flight Center**. *Further information may be found in NASA TM-82550 [N84-15866/NSP], "Some Properties of a Five-Parameter Bivariate Probability Distribution."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 20 on the TSP Card.
MFS-27061

Codes With Parity Conditions on Subsets of Coordinates

New theorems aid the search for efficient code alphabets.

A paper discusses the theory of finding the largest binary codes 2k bits in length, in which all words differ from each other in at least d places and in which words truncated by ignoring certain subsets of bit positions belong to shorter linear codes. This theoretical work was motivated by the search for binary codes for the American National Standard Code for Information Interchange (ASCII) control characters used in simple protocols for transferring files between microcomputers.

The general codes are characterized by the functions A, B, and C, that specify the size (that is, the number of code words) of a given code. Specifically, A (2k,d) = the largest size of a binary code of length 2k and minimum distance $\geq$ d. If each code word is required to contain an even number of ones in its first k and in its last k bits, then the size of the code is given by B (2k,d). If each code word is required to contain an even total number of ones (regardless of position), then the size of the code is given by C (2k,d). Because case B is included in case C and case C is included in case A, $B(2k,d) \leq C(2k,d) \leq A(2k,d)$.

The codes of case B are of principal interest in the solution of the ASCII problem, in which control characters are to be transmitted as pairs of 8-bit ASCII characters. Relying heavily on matrix and vector-space theory, the authors derive several theorems and lemmas about these codes, including notably the following:

- When the integer k is even, B (2k = 4n, d = 2n) = 8n, provided that a 4n-by-4n Hadamard matrix exists.
- When k is odd, then B (2k = 4n, d = 2n) $\leq$ 8n – 4, or = 8n – 4 if a 4n-by-4n Hadamard matrix exists.

The latter theorem is the main one and is applied to the construction of a code incorporating two eight-bit ASCII characters. Two bits are constants of the desired set of characters and are therefore discarded, leaving a total of 2k = 12 bits, of which two are parity bits. Since 4n = 12, n = 3, and the maximum number of words in such a code is given by $B_{max} = (8 \times 3) - 4 = 20$. This type of code enables the correction of up to 2 erroneous bits and the simultaneous detection of a third erroneous bit in two characters transmitted together.

This work was done by Ed Posner and Zinovy Reichstein of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Codes With Parity Conditions on Subsets of Coordinates," Circle 21 on the TSP Request Card.*
NPO-16572

"Who the heck wants to hear actors talk?"

Harry M. Warner
Warner Bros. Pictures, c. 1927

The future isn't what it used to be.

There's no future in trying to stop the march of progress. That's especially true when it comes to the science of communication. If it had been left to Harry M. Warner, we would still be watching silent films. Fortunately, there are people who know that the future lies in leading the way, tackling the impossible, and making things happen.

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Filter Bed of Packed Spheres

Spheres are sized and treated for the desired sieve properties.

NASA's Jet Propulsion Laboratory, Pasadena, California

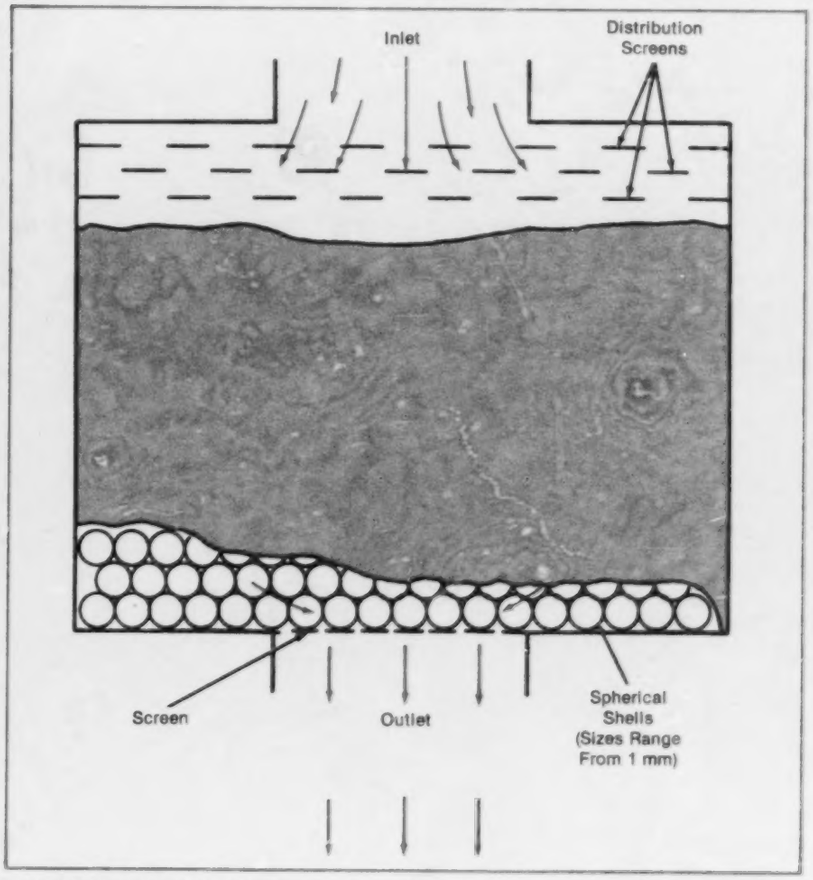
A proposed filter would be constructed from densely packed spheres restrained by screens (see figure). Hollow gas-filled plastic or metal spheres would normally be used. These can be manufactured within one percent or better diameter tolerance. Normally, all the spheres in a filter would be of the same nominal diameter.

The spheres could be sintered together, thereby eliminating the need for screens. In most cases, however, it is better to retain the spheres by screens alone, thereby making it possible to remove the spheres for cleaning, chemical treatment, or replacement.

The passages formed by the interstices between the packed spheres have well-defined widths due to the close control of sphere diameters. Therefore, such a filter could be used as a sieve to pass only particles smaller than a given size or to retain particles larger than that size. In the case of cells or other biological materials, the new filter may be preferable to older screen-type filters, which can damage the cells or other filtrate particles.

The spheres could be given special surface treatments, depending on the intended use. Coatings that have affinity for certain constituents (for example, blood or blood fractions) could be applied. Palladium could be used to filter hydrogen out of an effluent gas mixture. Catalytic coatings or multilayer, multipurpose coatings are also possible.

Given such design constraints as the maximum tolerable differential pressure, the desired flow rate, and the anticipated



Packed Spheres Retained by Screens form a filter or sieve. The dimensions and surface coatings of the spheres are selected to provide the desired physical and chemical properties.

particle-size distribution in the fluid, a filter might be designed by a suitable choice of the number of layers of spheres, the size of the spheres, and the dimensions of the container. The options available under the filter concept make it fairly easy to design for a specific application.

This work was done by Daniel D. Elleman and Taylor G. Wang of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 47 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 29]. Refer to NPO-15906.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Contrast-Sensitivity Research

The spatial-frequency spectrum of patterns changes the visibility of spatial phase differences.

A report presents a study of the visual effects of the frequencies of luminance patterns and particularly how frequency components affect the visibility of spatial phase differences over several octaves. The study should be of interest to researchers engaged in the development of algorithms relating to visual processing in robots, the incorporation of human factors in the design of visual displays, and the development of a set of rules the visual system uses to reconstruct a three-dimensional perception from a two-dimensional neural representation.

The psychophysical study made use of a visual-testing instrument (VTI), a minicomputer to control the VTI, and a cathode-ray tube to display the visual stimuli. The cathode-ray tube was surrounded by a light-green cardboard. The tests were governed by a two-interval, forced-choice paradigm. Both intervals contained test gratings of the same frequency added to the same background grating and differed only in the spatial phases between the test and background gratings. The difference between the spatial phases was fixed at 90° throughout the study. This difference was set by shifting the peak luminance of the test grating one-eighth of a period of the fundamental frequency of the background to the left (left-shifted stimulus) or one-eighth of a period to the right (right-shifted stimulus). Both single- and multiple-frequency backgrounds were used.

In the experiments, the spatial-frequency components over a four-octave range affected the visibility of spatial phase differences. When the spatial frequency of the test and background gratings differed by one octave or less, phase differences were more visible (in certain frequency combinations) than they were when the frequencies differed by more than an octave. Phase differences were visible at low contrasts over a three-octave range of test frequencies when the test and background frequencies were harmonically-related and when the spatial period of the background was wide.

Practice increased the ability of the test subject to discern the phase differences, primarily for test and background frequencies within one octave of each other. When such practice consisted of scrutinizing spatial windows of different widths, monitoring the directions of shifts in the positions of small luminance differences, and memorizing several different orderings of light and dark bars, it facilitated phase discrimination for multiple-frequency gratings, spanning a much wider range of frequencies than would otherwise be possible. These results are consistent with the notion that the visibility of phase differences is processed by some combination of even and odd symmetric cells in the striate cortex tuned to a wide range of different spatial frequencies.

This work was done by Teri A. Lawton of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "The Spatial Frequency Spectrum of Patterns Changes the Visibility of Spatial Phase Differences," Circle 39 on the TSP Request Card.*
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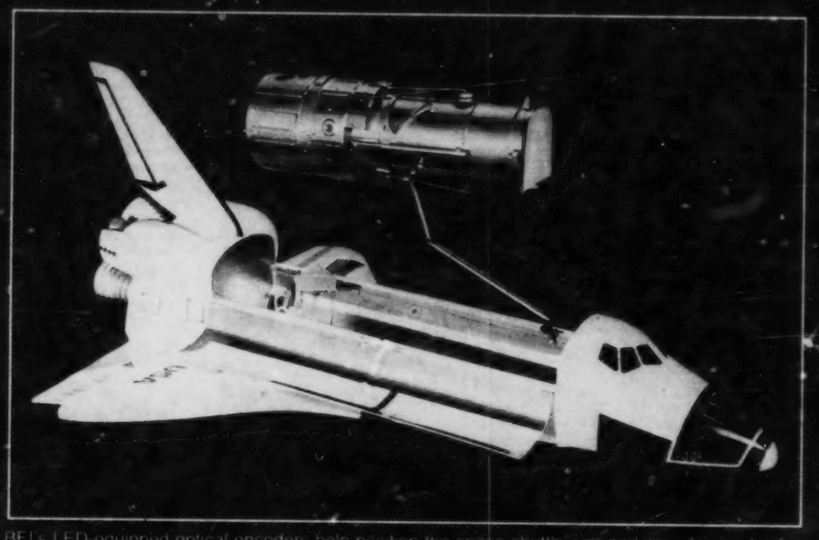
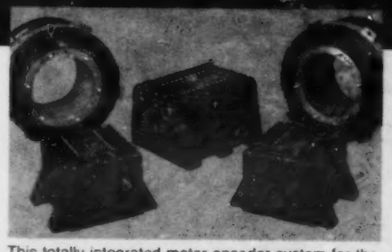
BEI's LED-equipped Optical Encoders. Proven thru Time and Space.

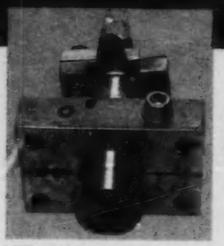


BEI's LED-equipped optical encoders help position the space shuttle arm and provides guide star position data on NASA's Hubble Space Telescope.

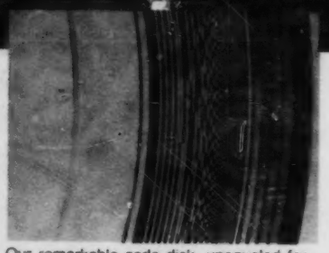


This totally integrated motor-encoder system for the Hubble space telescope provides resolution and accuracy to 21 bits.

The space shuttle's remote manipulator arm uses high-reliability BEI encoders.



LED read station with optics.



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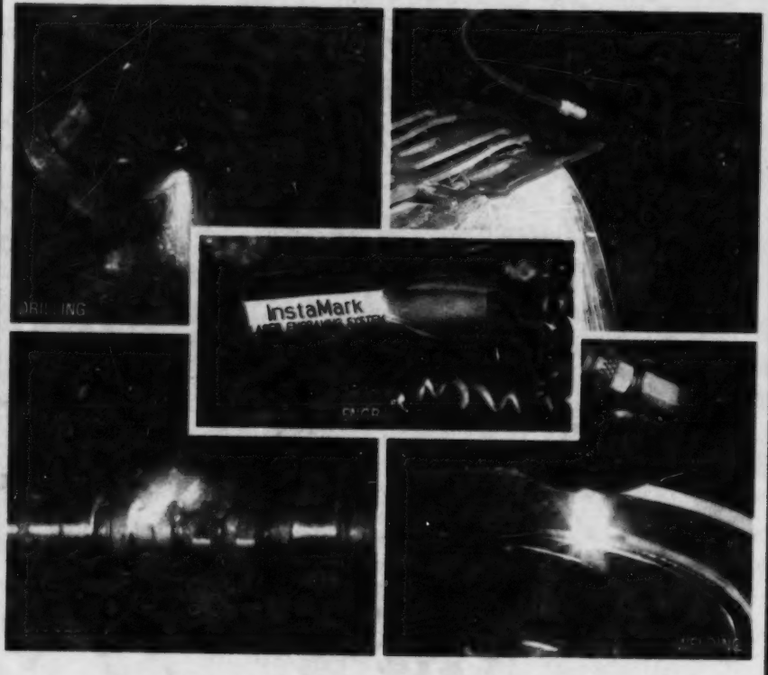

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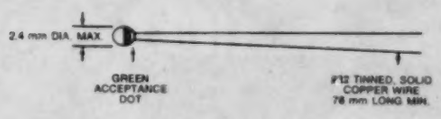

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I feel that, working for a NASA contractor, I should be able to submit items to Tech Briefs. *May I?*

Clark Dunson
Payload Engineer
Lockheed Space Ops.
VAFB, CA

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President
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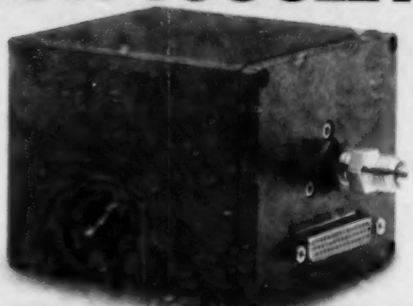

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Subject Index

This document was prepared under the sponsorship of the National Aeronautics and Space Administration. NASA Tech Briefs is published quarterly and is free to engineers in U.S. industry and and to other domestic technology transfer agents. It is both a current-awareness medium and a problem-solving tool. Potential products...industrial processes...basic and applied research...shop and lab techniques...computer software...new sources of technical data...concepts...can be found here. The short section on New Product Ideas highlights a few of the potential new products contained in this issue. The remainder of the volume is organized by technical category to help you quickly review new developments in your areas of interest. Finally, a subject index makes each issue a convenient reference file.

Further information on innovations—Although some new technology announcements are complete in themselves, most are backed up by Technical Support Packages (TSP's). TSP's are available without charge and may be ordered by simply completing a TSP Request Card, found at the back of this volume. Further information on some innovations is available for a nominal fee from other sources, as indicated. In addition, Technology Utilization Officers at NASA Field Centers will often be able to lend necessary guidance and assistance.

Patent Licenses—Patents have been issued to NASA on some of the inventions described, and patent applications have been submitted on others. Each announcement indicates patent status and availability of patent licenses if applicable.

Other Technology Utilization Services—To assist engineers, industrial researchers, business executives, Government officials, and other potential users in applying space technology to their problems, NASA sponsors Industrial Applications Centers. Their services are described on pages 28-29. In addition, an extensive library of computer programs is available through COSMIC, the Technology Utilization Program's outlet for NASA-developed software. See special section on computer programs on page 70.

Applications Program—NASA conducts applications engineering projects to help solve public-sector problems in such areas as safety, health, transportation, and environmental protection. Two applications teams, staffed by profesionals from a variety of disciplines, assist in this effort by working with Federal agencies and health organizations to identify critical problems amenable to solution by the application of existing NASA technology.

Reader Feedback—We hope you find the information in *NASA Tech Briefs* useful. A reader-feedback card has been included because we want your comments and suggestions on how we can further help you apply NASA innovations and technology to your needs. Please use it; or if you need more space, write to the Manager, Technology Transfer Division, P.O. Box 8757, Baltimore, Maryland 21240-0757.

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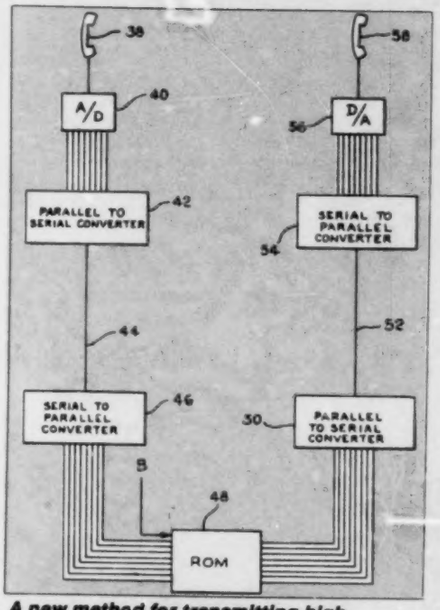
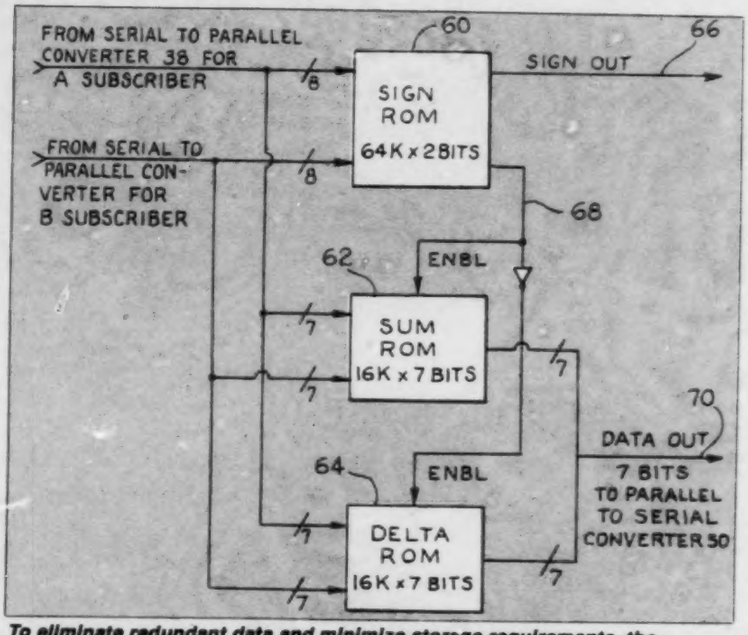
Mission Accomplished

Through the technology transfer process, many of the systems, methods and products pioneered by NASA are re-applied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.



A new method for transmitting high quality audio signals over long distances has been developed at Kennedy Space Center.



To eliminate redundant data and minimize storage requirements, the conference calling system utilizes a sign ROM, a sum ROM and a delta or difference ROM to determine the output-sign bit.

Kennedy Space Center's approach to technology development differs from that of its NASA counterparts. Compared to Langley, Lewis and Ames, for example, where research and development are long-standing traditions, Kennedy Space Center's programs are much more operations-oriented. And because the nature of these operations—spacecraft assembly and launch—is somewhat unique, Kennedy's technology development programs tend to result in similarly unique applications.

A case in point is the recently patented conference calling system developed by Frank Byrne, Kennedy Space Center's deputy director of information systems. Byrne's "Method and Apparatus for Operating on Companded PCM Voice Data" has the potential to link up to 2,000 people in a single conference call. While it's true that few organizations need to simultaneously involve 2,000 people in a conference call, it's also true that, for Kennedy's purposes, commercially available conference call systems are not quite up to par. For one thing, the transmitted audio signals tend to degrade in relation to noise when a large number of parties are involved, and secondly, this effect is heightened when the signal must be transmitted over long distances.

Ongoing commercial development efforts have addressed the signal-to-noise degradation, resulting in innovative digital signal-transmitting devices. While these devices reduce the amount of signal interference for a limited number of parties and over short distances, they still fall short of Kennedy Space Center's requirement to link a large number of people at varying distances with minimum interference.

Frank Byrne's development efforts addressed these particular requirements and resulted in a method for combining a multiplicity of signals with a minimal amount of noise. The heart of his invention is an innovative read-only memory (ROM), which both reduces the number of signal-processing steps and eliminates redundant data, minimizing the ROM's storage requirements and resulting in a clearer signal.

To further minimize interference and to facilitate transmission over long distances, Byrne incorporated a multiplying-ROM subsystem which compensates for differences in signal amplitude between system subscribers. The subsystem multiplies the signal's amplitude prior to processing to increase its volume, and enables subscribers at varying distances to receive signals of equal clarity.

The new conference calling system will advance Kennedy's already sophisticated communications network. In addition, it's expected that the signal-combining technology will be licensed and adapted for commercial purposes, eventually replacing current systems and enabling the general public to talk shop along the leading edge of technology. □

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Our Modular Azimuth Positioning System contract also applies RLG technology to land applications. Similar work using this technology is being conducted for application to naval surface ships and missiles such as SRAM II and JTACMS, and Strategic Defense Interceptors such as HEDI and ERIS.

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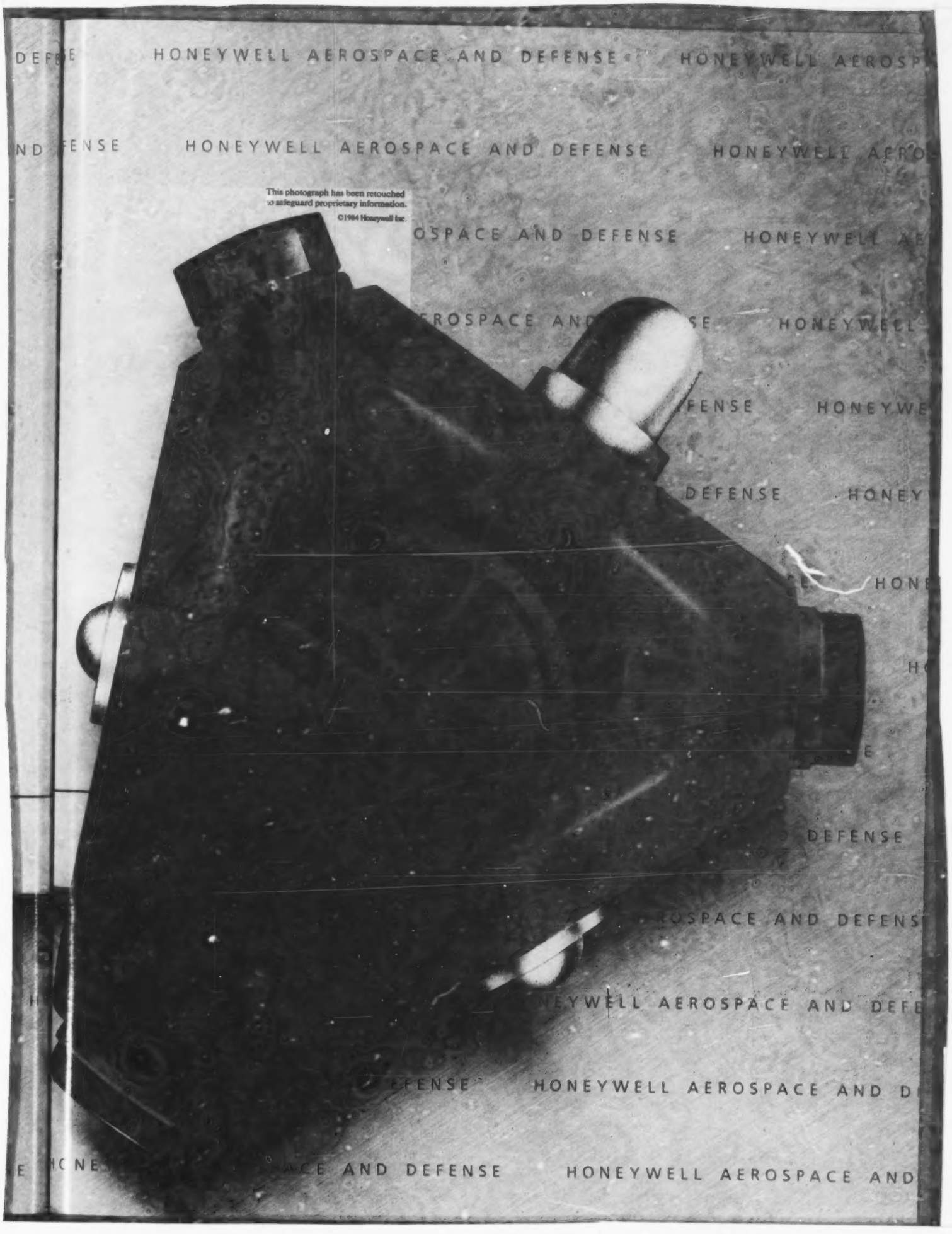
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FROM MERCURY TO SPACE STATION.

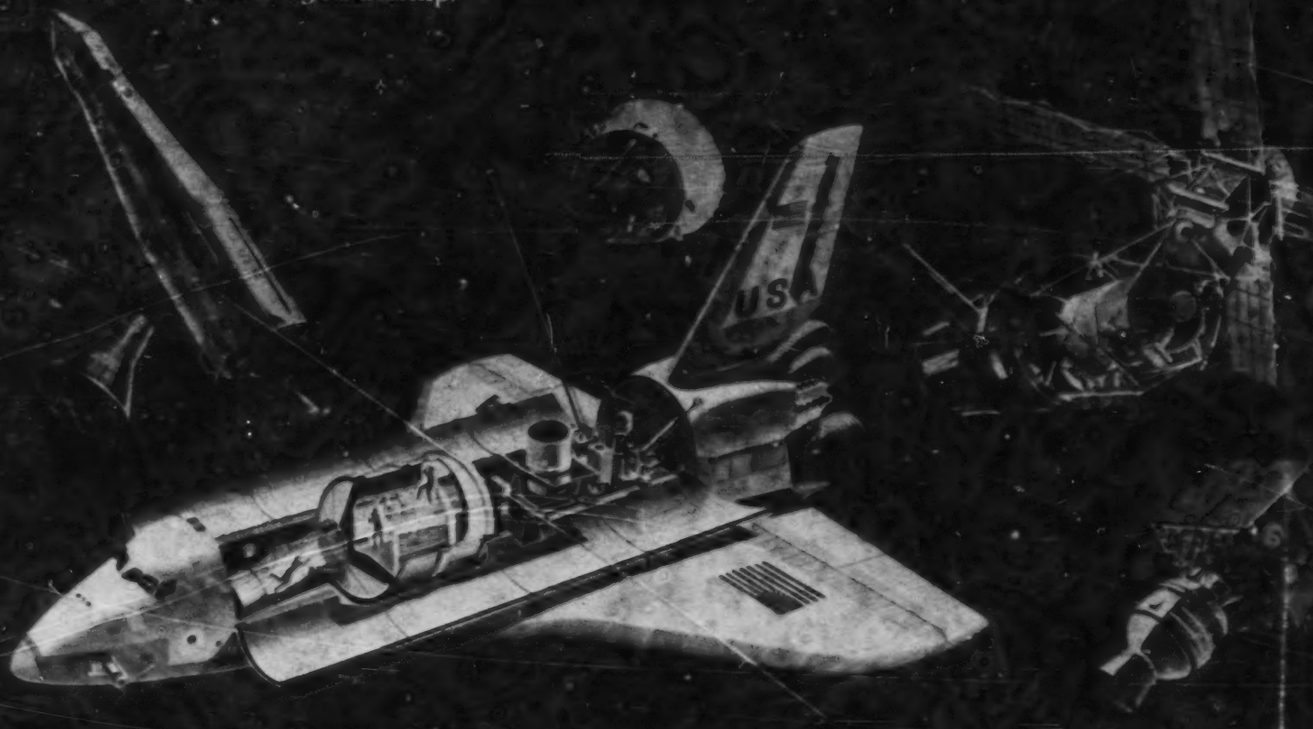
For sheer thrill of accomplishment for an industrial team, there probably never has been anything to compare with the first flight of the Project Mercury Capsule into space.

—Our 1961 Annual Report

Since NASA was founded, we have been engaged in an adventure beyond all that civilization had earlier dreamed. Beyond what we could imagine in 1961 when we listened breathlessly to Astronaut Alan Shepard fly our Mercury Spacecraft into history.

McDonnell Douglas support for a human role in space has never wavered. It is dramatically demonstrated by the spacecraft we've provided for NASA — Mercury, Gemini and Skylab; the launch stages for Apollo, and work on the Space Shuttle and its payloads.

Now we are working with NASA to make Space Station a reality. As we celebrate a quarter-century of success and achievement, struggle and sacrifice, we are rededicating our efforts to America's spacefaring leadership.



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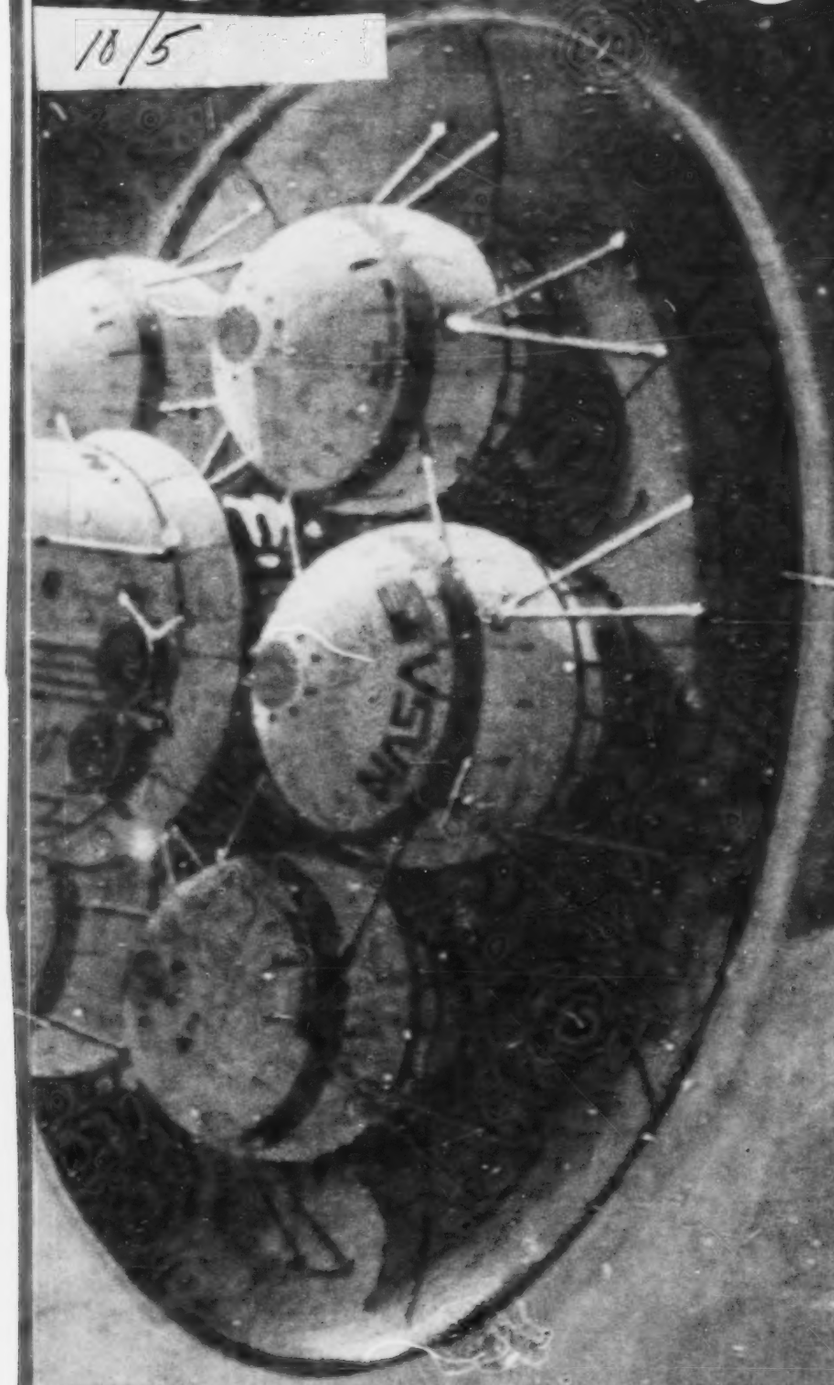
National Aeronautics and Space Administration

September/October 1986
Volume 10 Number 5



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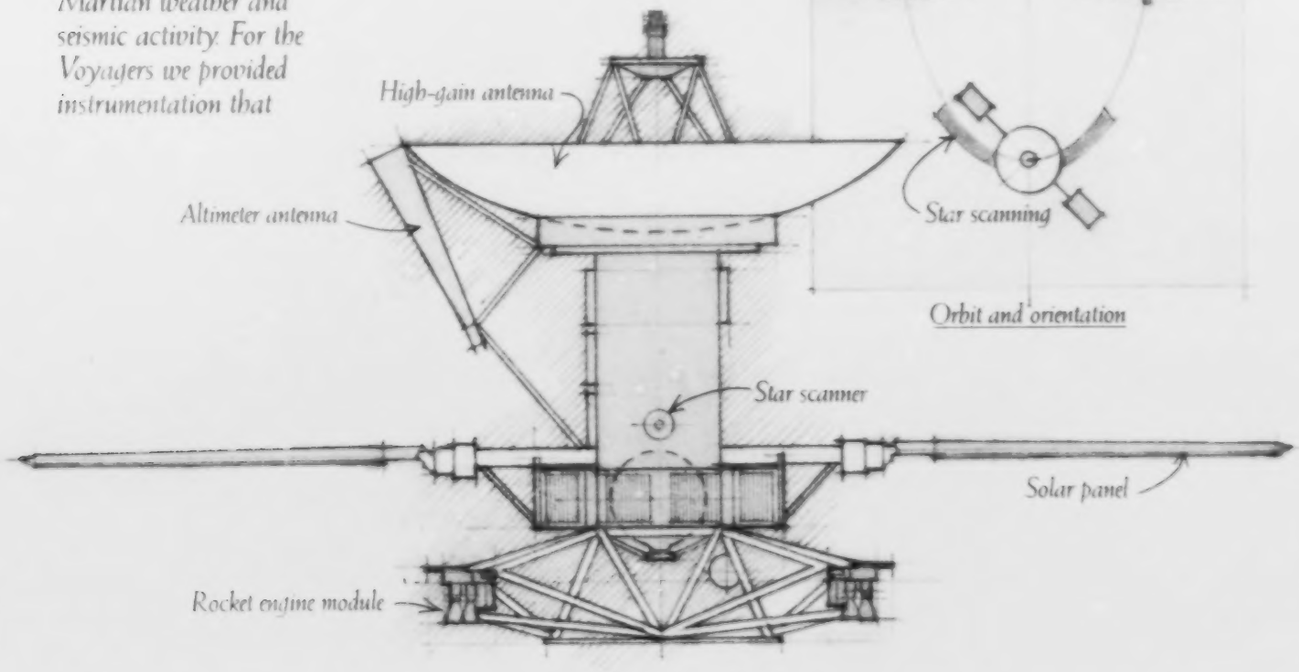
Pioneering the Space Frontier:

The Report of the National Commission on Space

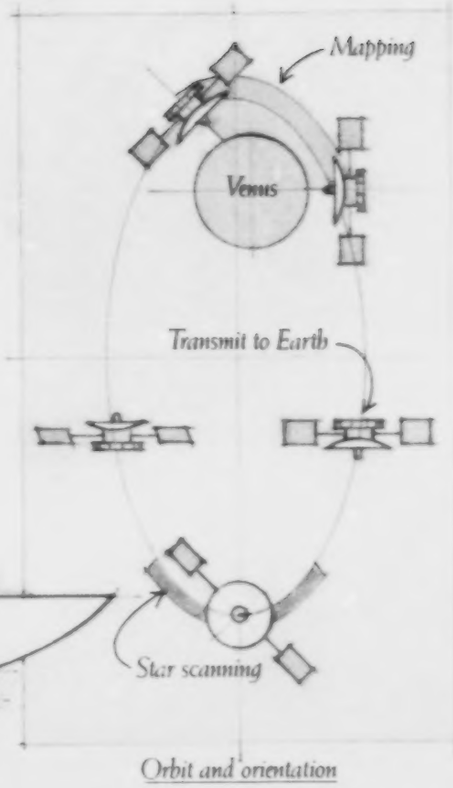
NAS 1.28/3:

In space: looking back to look forward.

What can the nature and origin of the universe tell us about the future of Earth? To help answer that question, we make craft and instruments for traveling billions of miles in space and seeing as far as 15 billion years back in time. Martin Marietta was the integrator and builder of two Viking landers, which sent back remarkable photos of the surface of Mars, examined soil samples, and studied Martian weather and seismic activity. For the Voyagers we provided instrumentation that reported on electromagnetic activity near Jupiter and Saturn—Voyager 2 went on to Uranus, some 2 billion miles from Earth. That was nine years after launch; next destination, Neptune, in 1989. These are but a few results of Martin Marietta's ability to create survivable, mystery-solving craft and their instruments—from concept through mission completion.



Magellan Spacecraft



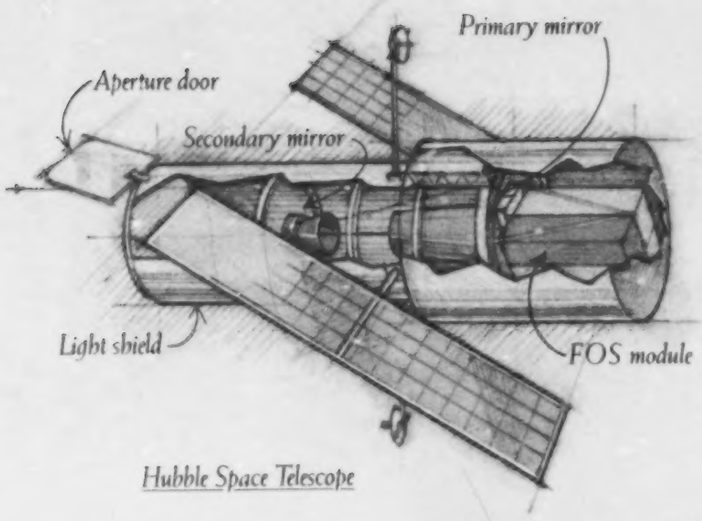
Orbit and orientation

Mission: map Venus.

From orbit, Magellan's radar will penetrate the planet's thick, gaseous cloud cover and send back photo-like images of nearly 90% of its surface. Our role: design, integrate, build and test the craft.

Viewing the infant universe.

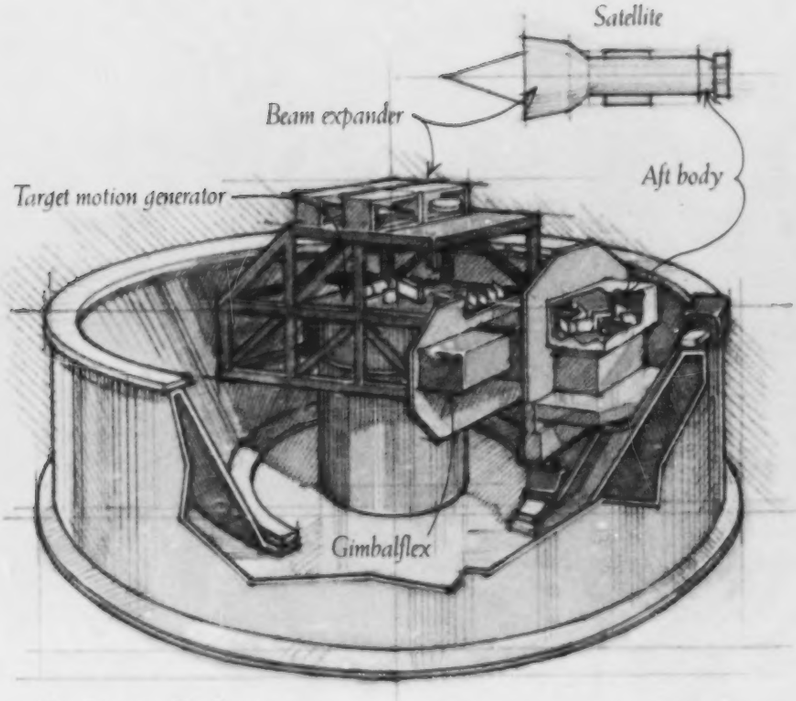
For the Hubble Space Telescope we are providing the Faint Object Spectrograph (FOS), which will see objects up to 15 billion light-years away. Since the universe is estimated to be 18-20 billion years old, astronomers will witness events close to its birth.



Hubble Space Telescope

The fine points of fine pointing.

Precisely controlled, space-spanning energy delivery and collection systems create difficult pointing and retargeting challenges, which we can now simulate. This new lab is working toward the precision to zero in on a football-size object 3,000 miles away, in support of the Strategic Defense Initiative research program.



Fine Pointing Simulator

MARTIN MARIETTA

6801 Rockledge Drive, Bethesda, Maryland 20817, USA

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National Aeronautics and Space Administration

SEPTEMBER/OCTOBER 1986
Volume 10 Number 5

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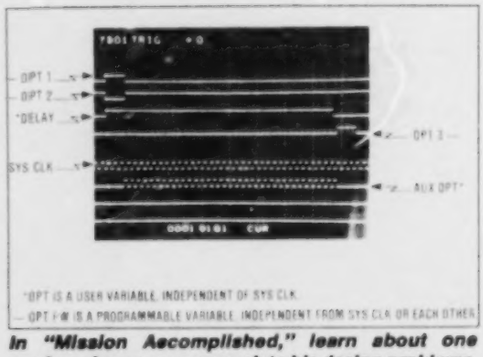
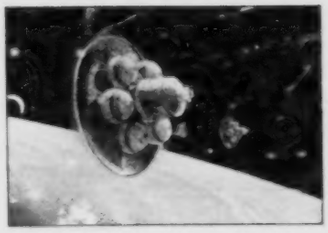


In "Mission Accomplished," learn about one engineer's proven approach to his design problems. Shown here is the timing diagram to Joseph King's multiple output sequencing controller, described on page 131.



ARTIST: ROBERT McCALL, COPYRIGHT 1986, BANTAM BOOKS, INC.

Transfer vehicles slowing down in the earth's upper atmosphere as they return to the future Space Station. A large ceramic disk serves as the aerobrake. Behind the disk are six propellant tanks and a cylindrical crew module.

The Report of the National Commission on Space, reviewed in this issue, predicts exciting developments in space during the next half-century . . .page 10.

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Technical Section

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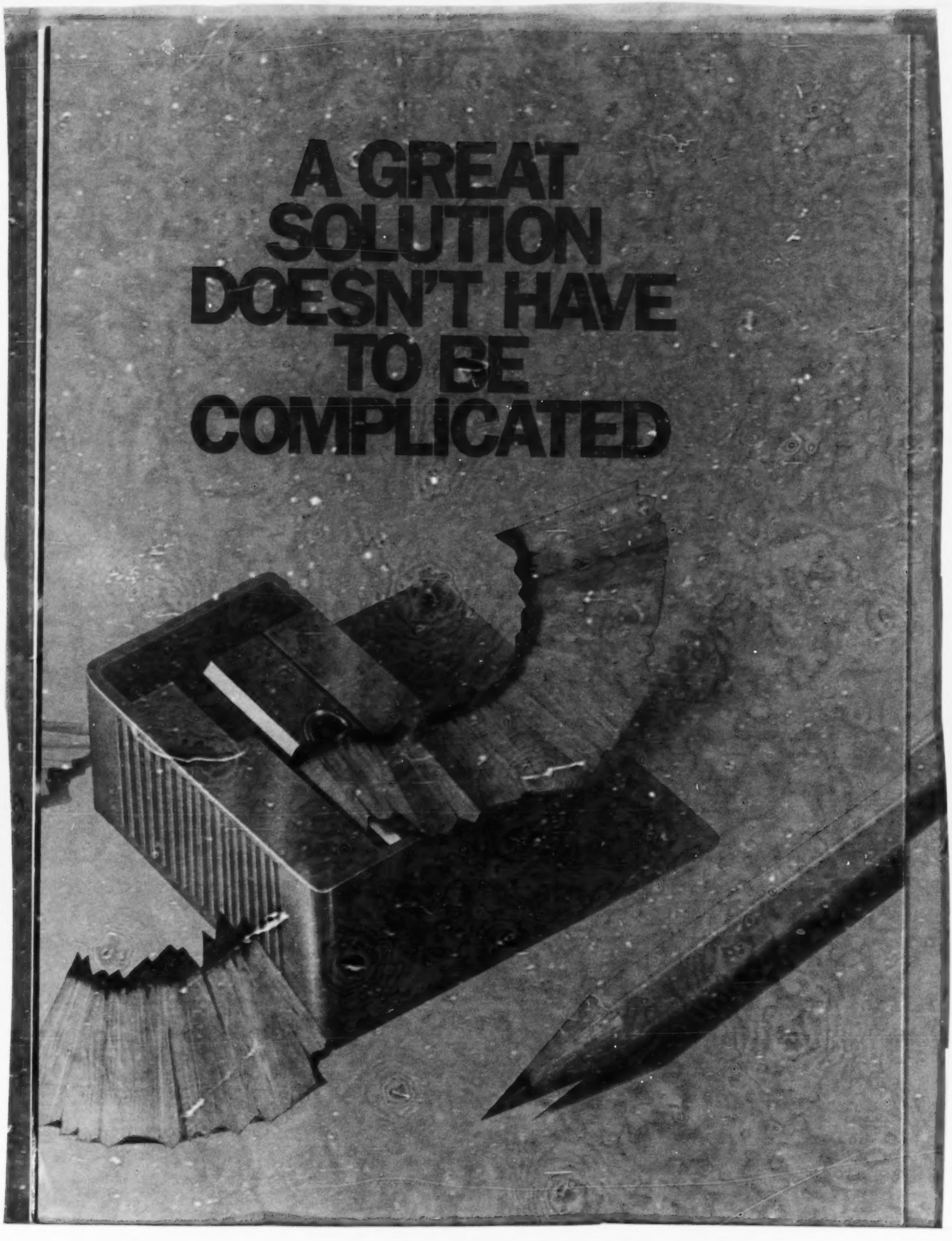
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DOESN'T HAVE
TO BE
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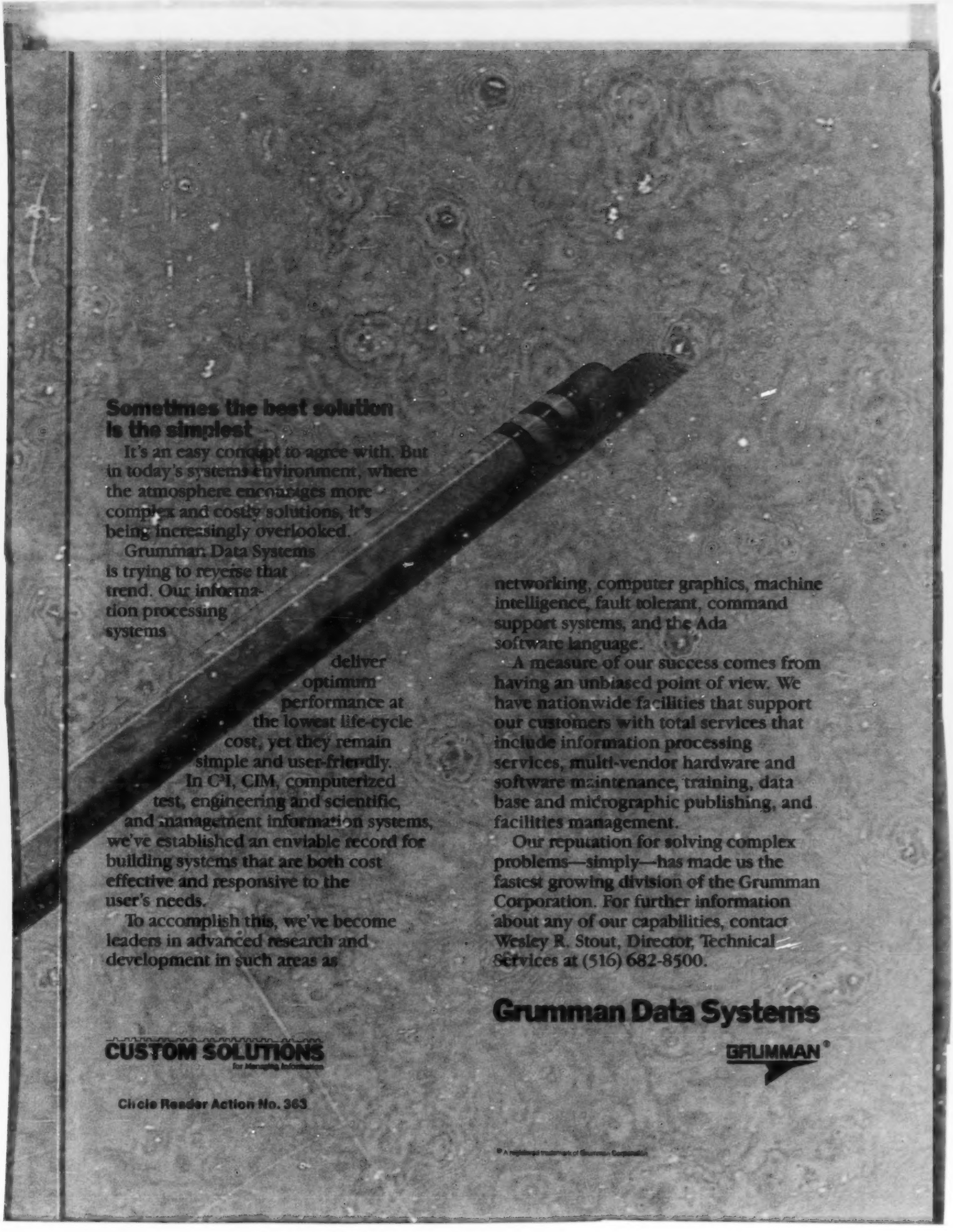

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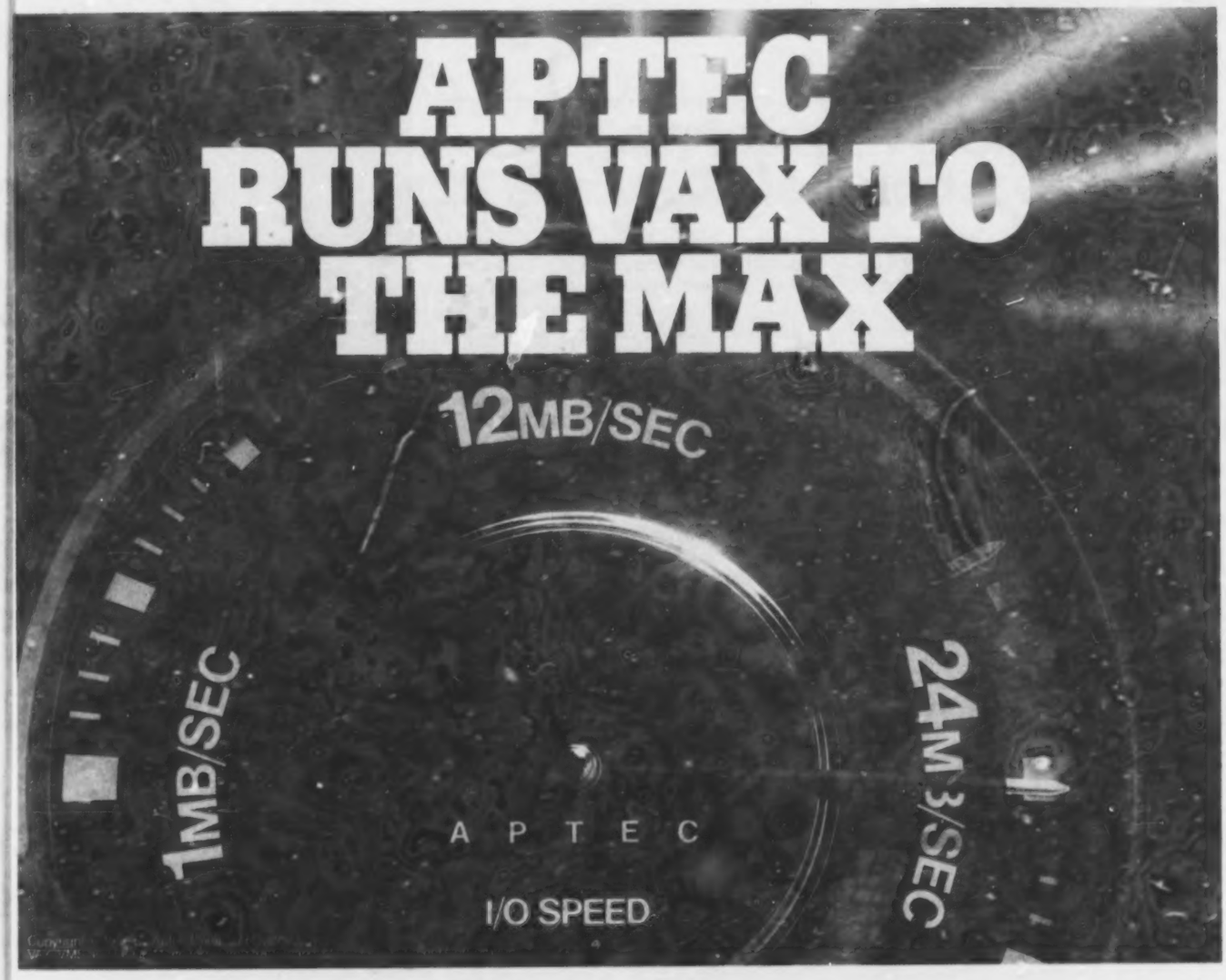

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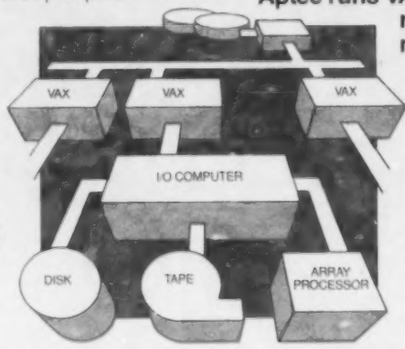

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Circle Reader Action No. 314

Editorial Notebook

The National Commission on Space

The cover story this month is a synopsis of the President's Commission on Space's predictions for the next 50 years. The possibilities are staggering. The great leaps we have made in the past 50 years will be dwarfed by what happens in the next, and technology as always will not only be the driving force, but also one of the major end results.

I hope you'll find the article interesting, and I hope too that it will move you to buy the report, read it, and then let your elected representatives know how you feel about it. It is my personal opinion as a private citizen that this is the time to support a national effort to pioneer the space frontier. In constant dollars NASA funding is approximately half of what it was during the Apollo days.

As I sat down to write this editorial notebook, I noticed that *The New York Times Magazine* had a feature story on the billions of dollars of benefits, and the technological break-throughs that will in all probability accrue through SDI. It is a continual irritant to me that publications like *TNYT* can somehow be aware of the possibilities in SDI, yet are simultaneously able to ignore the reality of the successful transfer of technology that NASA has already achieved. I almost used the phrase, "It has never ceased to amaze me," but that would not only have been hackneyed, but untrue. I have unfortunately long since become inured to the situation.

Under the heading of errata, in our article on KSC last issue, we mentioned that the "crawler-transporter weighs a whopping 3½ million tons." Well, it's heavy, but it doesn't whop quite that hard. The crawler weighs 6 million pounds, the orbiter launch platform another 8 million pounds, and the Orbiter, including the SRBs, but excluding the liquid fuel for the main engine which is pumped in at the launch site, weighs 3 million pounds, for a grand total of seventeen million pounds. Perhaps this and Palmdale's instant relocation was due to the fact that we did so much with mirrors in that issue. (See Letters, page 127.) □

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Product/Research Developments®

Fifth of a series

General

With the emphasis on productivity and economy these days, every possibility for savings should be investigated.

Some of 3M's more than 40,000 products provide significant economies on a high level of sophistication. Others are simpler in design — but no less economical.

Here are a few that may help you reduce your budget.

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The new *Inspex* Dry X-Ray Film brings much-needed speed and productivity to non-destructive testing.

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Conclusion

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A possible joint U.S./Soviet unmanned Mars mission is envisioned here, with the U.S. providing a prospector to collect soil samples, and the Soviets providing the spacecraft to return them to Earth. **Below:** *An unmanned spacecraft leaving the solar system. In the foreground is Pluto, in the background, its moon Charon.*

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DATELINE 2035:

The Report of the National Commission on Space

Fifty years. Depending on your point of view, it can constitute a lifetime or pass in the blink of an eye. Looking back, it is the measure of recent history, the heart of the twentieth century, the post-modern era; looking ahead, it is the future, the threshold of a new millennium, and the inspiration for ongoing speculation by a new breed of social scientist, the futurist.

In the Space Age, the future tends to attract more attention than the past, so it is fitting that Congress, in 1984, commissioned a study to map civilian space goals for the next fifty years. But ironically, "Pioneering the Space Frontier," the report of the National Commission on Space, appeared at almost the same time as the Rogers commission report on the Challenger accident. Without a doubt, the Rogers commission report garnered the lion's share of public attention and focused it firmly in the uncertain present.

Historians and futurists alike view the the Challenger accident as a critical juncture in the United States space program. Because one of the functions of history is to put crisis in perspective, the Rogers commission report is essentially a historical document. On the other ►

2035

hand, the report of the National Commission on Space, which was practically complete prior to the Challenger accident, is in the wake of Challenger perhaps even more futuristic than its authors intended.

In any event, the report of the National Commission on Space, whose timing has been called alternately "ghastly" and "fortuitous," and whose content has been labeled "ambitious," is a 211-page compendium of civilian space strategies and goals for the 21st century. The report was prepared by the fifteen distinguished members of the National Commission on Space, chaired by Dr. Thomas O. Paine, former NASA administrator and former president of Northrop Corporation. The commission's recommendations were based in part on a series of fifteen public forums held in cities throughout the U.S. during 1985. Over 1800 people attended these forums, and most took advantage of the opportunity to present their personal points of view to the commission.

Bantam Books published the report in late May and it is currently available in bookstores nationwide for $14.95. Here we've highlighted some of the report's recommendations for a bold 21st-century civilian space program.

The View From Here

"To lead the exploration and development of the space frontier, advancing science, technology and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars." That, in brief, is the recommendation of the National Commission on Space to Congress and the President regarding what should be the goals of the nation's space program in the 21st century. To accomplish these goals, the commission recommends an approach based on three mutually-supportive thrusts: space science, space exploration and settlement, and the development of space enterprises. The report stresses that the success of this approach hinges on a commitment to the research and development of enabling technologies, particularly a space transportation system that ensures low-cost and regular access to space.

In the commission's view, the next generation space transportation system should be comprised of two different types of launch vehicles, one optimized for cargo and therefore very low-cost, and the other possessing a manned capability for less frequent launches at a higher cost. The cargo-carrying vehicle would evolve from current shuttle technology, and the passenger vehicle would be either an aerospace plane or an advanced rocket system. The commission recommends that a final decision on which manned option to pursue should be made only after preliminary R&D on both vehicles has been completed.

With regard to private sector involvement in the space transportation system, the commission, again citing the cost-cutting factor, urges that the next generation space vehicles be developed by the government but designed for eventual operation by the private sector.

Once a reliable space transportation system is in place, the commission foresees the paving of a highway to space, where a network of outposts will be established to enable long-term and in-depth space exploration and eventual settlement. Key to this plan is an Earth spaceport, which would be a follow-on to the international space station. Like the space station, the spaceport would be based on a modular design concept and located in low-earth orbit. It would be the first space airport, a transport node where spaceships could be berthed, cargo could be stored and passengers could disembark. ►

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In the foreground is an aerospace plane approaching the Earth Spaceport. The Spaceport is receiving material from an unpiloted Cargo Transport Vehicle in the lower left-hand corner. A Transfer Vehicle is returning to the Spaceport from the moon.

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Top: ***An astronaut leaves a transfer vehicle for a closer look at an asteroid. A Mars settlement in the 21st century.***

The commission envisions locating other spaceports in lunar orbit, at the L1 libration point between the earth and the moon, and perhaps eventually in orbit around Mars.

Establishing a network of spaceports would provide bases from which manned exploration missions and eventual settlements on both the moon and Mars could be launched. Prior to this, the commission's report suggests a series of advanced space science missions to complete the surveys and sampling missions begun by the Ranger, Surveyor and Viking spacecraft, and Apollo astronauts.

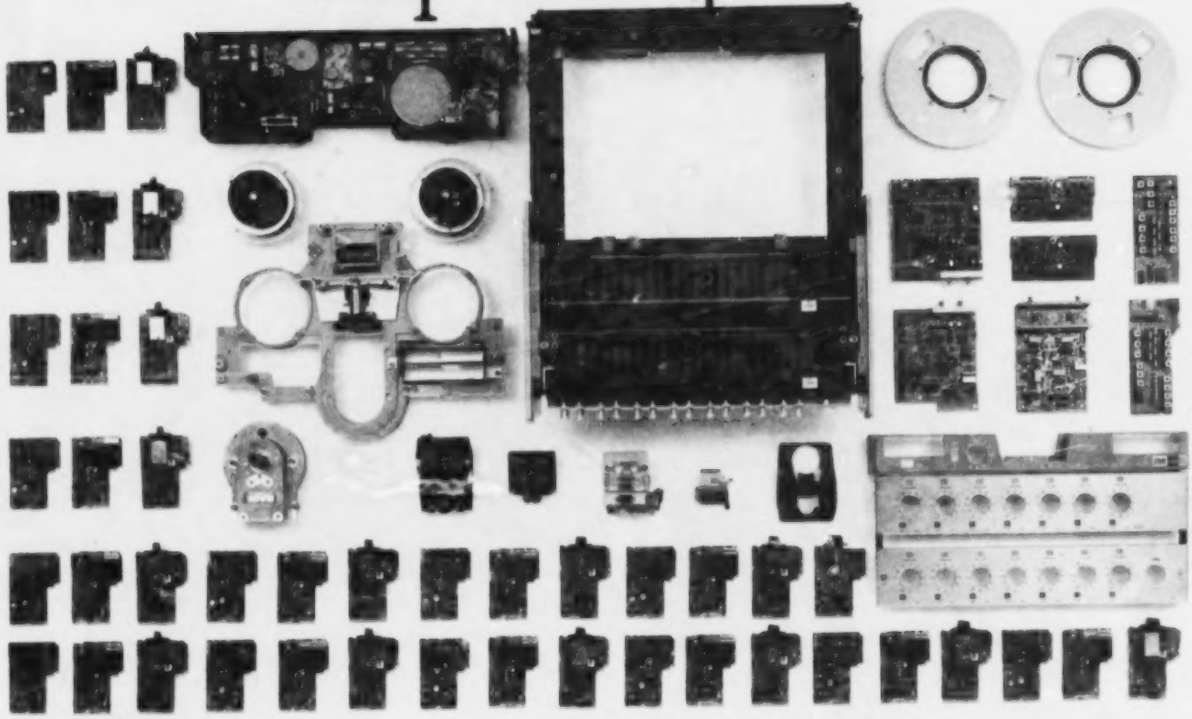
The commission recommends that the U.S. send a robotic lunar prospector to the moon to conduct a low-orbit survey of the entire surface of the moon, especially its polar regions. It also recommends lunar probe missions to drive penetrators into the lunar surface for further analysis of lunar material. Then, the report states, "it will be time for people to return to the moon . . . not only for brief expeditions, but for longer, systematic explorations; eventually, we should come to stay . . . establishing human-tended lunar surface outposts, primarily for a variety of scientific studies."

The View from There

Beyond the moon, the commission has singled out Mars and its moons, Phobos and Deimos, for scientific and eventual manned exploration. It recommends that the U.S. launch a sample return mission to the red planet early in the 21st century, and mentions a manned follow-up mission as a candidate for an international endeavor linking the U.S. and Soviet space programs.

Asteroids should also be investigated, according to the report, to determine what mineral resources they may yield to 21st century space prospectors. A number of accessible earth-crossing asteroids have already been identified by astronomers, and there is evidence to suggest that ►

Rip Us Apart



Before you buy a portable instrumentation recorder, Racal would like you to consider a simple truth—A machine is no more than the sum of its parts.

And the fact is, better parts cost more. Or, put another way, cheaper usually means cheaper.

But the choice is tough—do you recommend a merely adequate machine, just good enough for that one project, and save a few dollars? Or, do you spend that extra few percent and get reliable, flexible performance for years to come?

Frankly, we think, your data deserves the best recorder.

Here's how to justify one.

THREE REASONS WHY THE FIRST LAB QUALITY PORTABLE RECORDER IS STILL THE BEST

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Store Range models also let you choose up to 14 channels, at speeds of 15/16 to 60" per second.

Then there's our phase locked-loop, DC direct drive servo, wraparound capstan tape drive with balanced spool tension and no pinch rollers. Not to mention off-tape servo control.

Taken together, all that just means unmatched time base stability with almost no skew.

CHECK THE SPECS THEN CHECK THE REST

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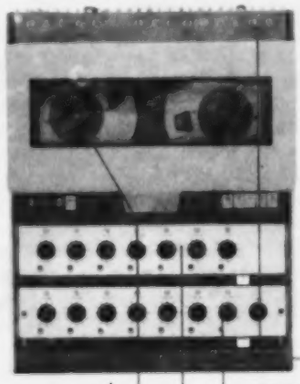
In fact, we offer the best signal to noise ratio and flutter available. But there's more to buying—or selling—a recorder than specsmanship.

That's why we use a rigid alloy casting for Store Range's chassis where most make do with stamped, spot welded sheet metal.

No belts, gears or pulleys means no belts, gears or pulleys ever wear out.

And modular construction let us disassemble the Store Range in this ad in about 45 minutes.


AC or DC operation
DR or FM recording
IRIG/ISO compatible
Servo controlled tape drive provides unmatched time base stability, almost zero skew.

Assembly takes 15 minutes more. What's more, head replacement doesn't mean tricky aligning.

It's all part of a twenty year development program by one of the world's largest electronics companies to make Store Range recorders tough, reliable and accurate.

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Lots of great ideas work well on paper.

You should demand a recorder that works well where you work.

Because in the real world, the ultimate test of a recorder is how close the signal that comes out is to what you put in.

It's that simple.

Before you buy a recorder, even if it's for just that next project, see which one works best. Then think about which one will work best in the long run.

We think you'll agree with 7,000 Store Range users and choose Racal.

Because no one else measures up.

Call Shirley at Racal to get more information or a Store Range demonstration.

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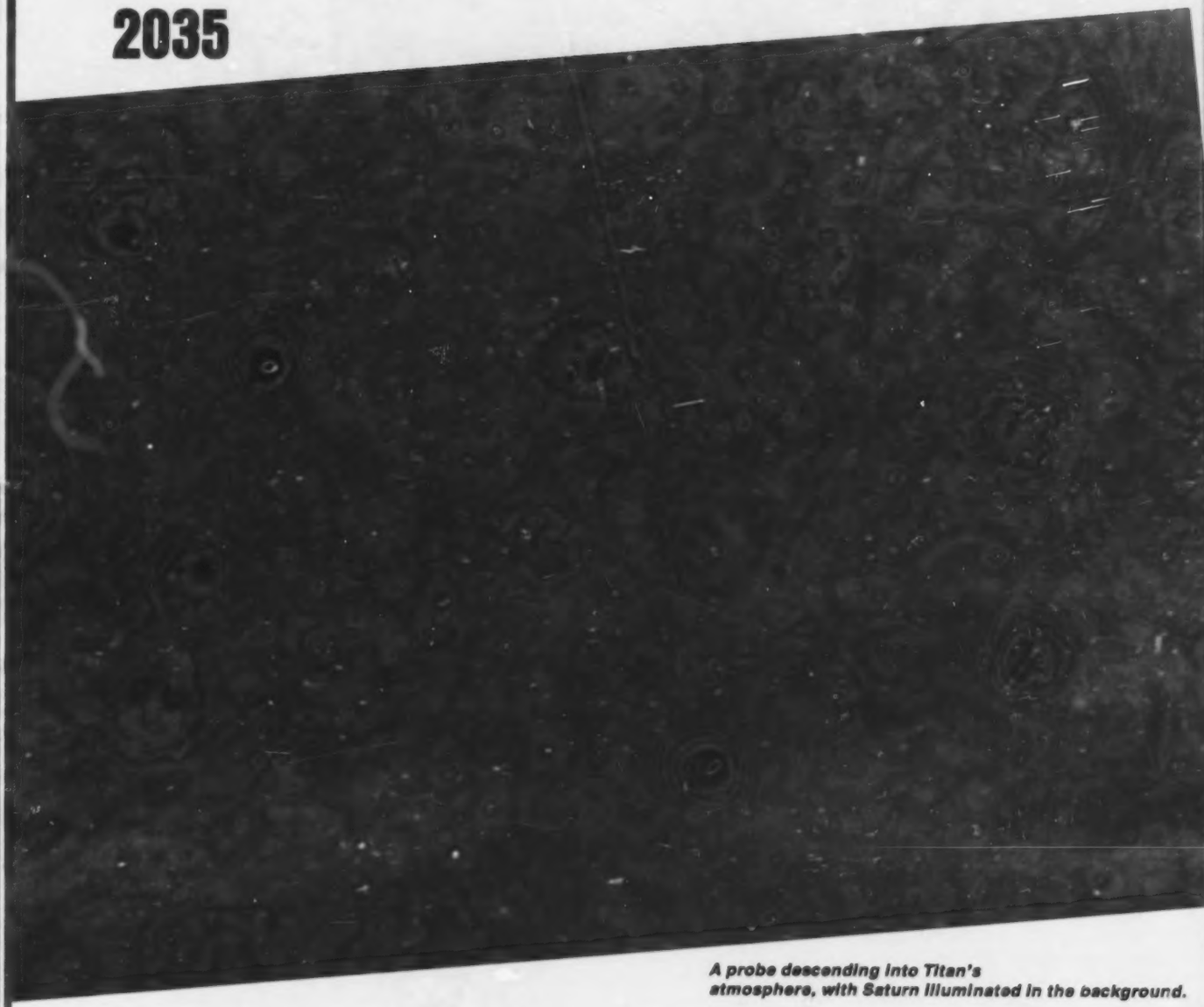

A probe descending into Titan's atmosphere, with Saturn illuminated in the background.

some of them may contain carbon, nitrogen and hydrogen. The report urges the expansion of the search for readily-accessible asteroids and robotic prospector missions to selected asteroids.

The fact that space is an as yet untapped source of natural resources and raw materials becomes important in light of the third of the commission's three recommendations: developing space-based commercial enterprises. Also, in order to sustain human outposts and settlements in space, the commission strongly recommends that long earth-based lines of supply be eschewed in favor of "living off the land" in space.

According to the report, there are three categories of space enterprise that will be viable in the world of 2035: supporting industries on earth, space industries with markets on earth and space industries with markets in space. Privately owned launch vehicles, facilities and related support services, such as maintenance, repair, fuel and communications are examples of supporting industries on earth.

A few examples of space industries with markets on earth currently exist, chief among them the satellite communications industry. Remote sensing, which facilitates the observation and management of crops and mineral, water and wildlife resources, is another potentially viable space industry now developing markets on earth. And microgravity materials processing and manufacturing are other potential space-based industries whose possibilities are already being examined by a number of earth-based companies. Solar power satellites capable of intercepting solar energy and transmitting it to earth are also being assessed in terms of their economic and technical feasibility.

Space industries with markets in space is still a speculative category at this point, but speculations abound. Mining raw materials on the moon, asteroids and on the moons of Mars, and then purifying these materials for use as propellants and in space-based manufacturing and construction is the approach suggested by the commission's report.

Such a brief overview of the report of the National Commission on Space does not really do justice to its far-ranging, well thought-out and ultimately visionary recommendations. In spite of its often heavy-handed, textbook style, the report is well organized and well illustrated. The ideas it presents are fascinating and its strategies based on evolutionary steps sound feasible.

Predicting the future is an age-old human activity, but systematically plotting its course is a relatively new, perhaps even Space Age, development. And considering the uncertainties that surround the nation's space program at present, it's certainly heartening to know that the future is still within our far-reaching grasp. □

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Wyle Laboratories is playing an important role in the development of the Space Station. As a team member with Martin Marietta, we are responsible for payload accommodations analysis and mission modeling for the U.S. Laboratory.

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Wyle has in-depth experience in defining and assessing user requirements and developing functional hardware and systems to meet user needs. Our translation of research objectives into workable integrated systems represents a valuable asset in the successful development of the Space Station.

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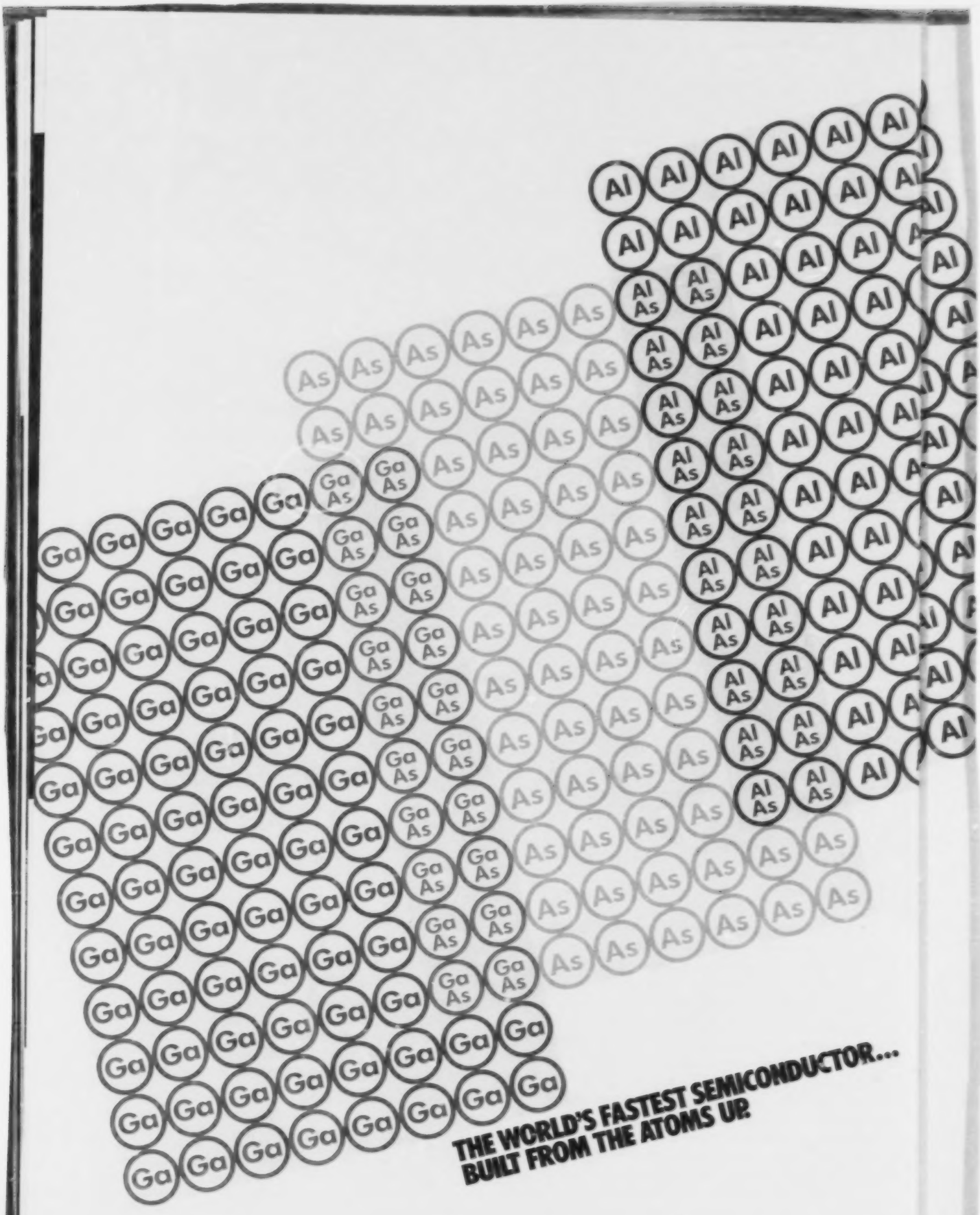

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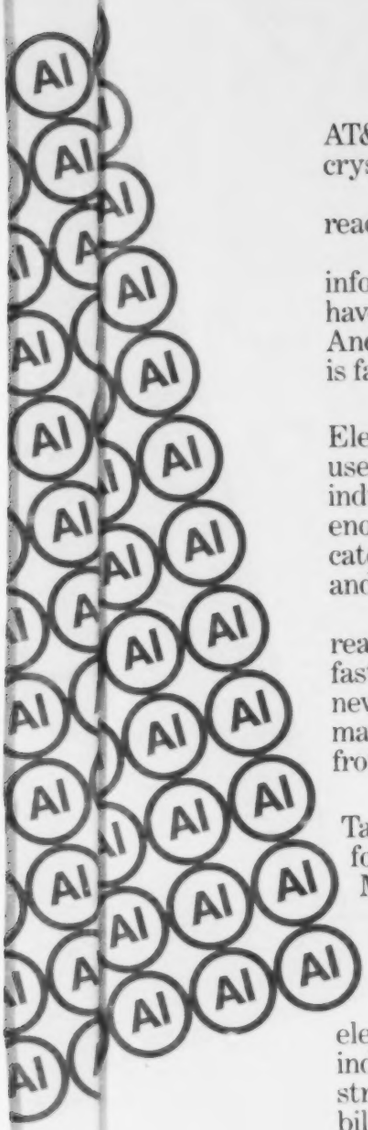
BUILT FROM THE ATOMS UP.



AT&T is building semiconductor crystals atomic layer by atomic layer.

The reason? To help electrons reach their full potential.

In our world of rapidly increasing information needs, the more data we have, the faster it has to be processed. And today, the key to faster processing is faster electrons.

Speed Is Of The Essence

Electrons in silicon—the most widely used material in the semiconductor industry—move quickly. But not quickly enough for many increasingly sophisticated applications, like real-time speed and image processing.

Now, silicon has just about reached its electron speed limit. For faster electrons to meet special needs, new materials are the key—new materials, not found in nature, built from the atoms up.

Going Flat Out With Atoms

Tailor-making new materials uses a form of atomic spray painting called Molecular Beam Epitaxy (MBE).

Invented and perfected by AT&T Bell Laboratories scientists, MBE creates ultra-thin, extraordinarily uniform films of selected elements. To prevent contamination, individual layers are sprayed onto a substrate in a vacuum containing 100 billion times fewer atoms than in the earth's normal atmosphere.

Finished films are uniformly flat to plus or minus one atom in depth.

Electrons That Move Like Rockets

In one application, AT&T constructed material using crystal layers of gallium aluminum arsenide and gallium arsenide. The gallium arsenide was kept pure, while the gallium aluminum arsenide layer was seeded, or doped, with carefully controlled impurities—sources of needed electrons.

These electrons are drawn in droves to the face of the pure layer. Here, unimpeded by impurities, electrons can rocket across the transistor's gate at 20 million centimeters per second—almost three times as fast as in today's silicon semiconductors.

Spray painting with atoms.

Using this new material, AT&T scientists collaborated with colleagues at Cornell University to set a transistor speed record. The device switched a logic circuit on and off in 5.8 picoseconds (trillionths of a second)—that's 170,000,000,000 times in a single second.

Putting The Future On The Beam

Molecular Beam Epitaxy has also enabled Bell Labs to produce a semiconductor that replaces electricity with... light.

Built of 2,500 precise, alternate layers of gallium arsenide and gallium aluminum arsenide, the chip contains four photonic switches that are turned on and off by light beams, much the way electronic transistors are activated by electrical charges.

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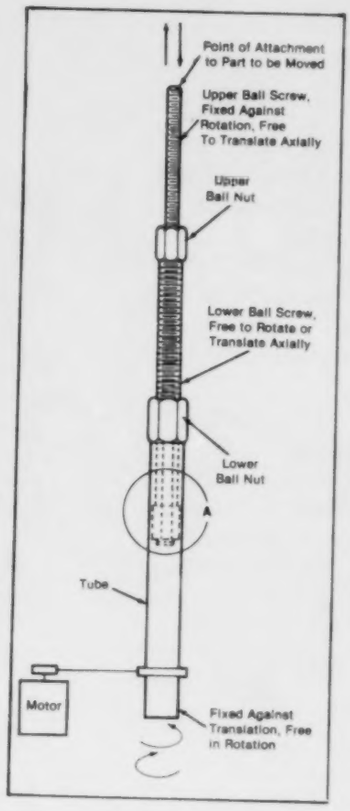
The right choice.

New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 29). NASA's patent-licensing program to encourage commercial development is described on page 29.


Point of Attachment to Part to be Moved
Upper Ball Screw, Fixed Against Rotation, Free To Translate Axially
Upper Ball Nut
Lower Ball Screw, Free to Rotate or Translate Axially
Lower Ball Nut
A
Tube
Motor
Fixed Against Translation, Free in Rotation

Shock-Absorbent Ball-Screw Mechanism

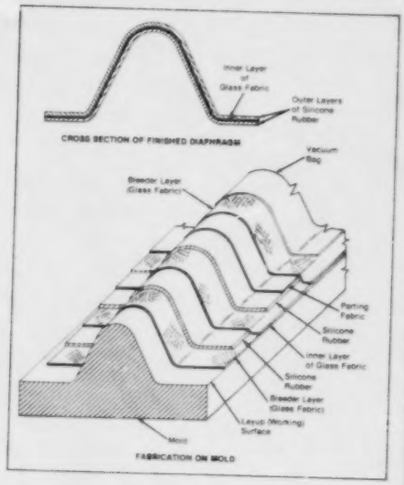
An actuator containing two ball screws in series employs Belleville springs to reduce impact loads, thereby increasing its life expectancy. The mechanism uses Belleville springs as the shock-absorbing elements because Belleville springs have a good energy-to-volume ratio and are easily stacked to attain any stiffness and travel. In addition to the two ball screws, the mechanism employs two ball nuts, a tube, and a drive motor (see figure). When the tube is rotated, the lower screw rotates or translates, thereby translating the upper screw axially so that it raises or lowers a part attached to the upper tip of the mechanism. A set of three springs within the lower screw of the ball-screw mechanism absorbs the impacts that result when the parts reach their upper and lower limits of movement.

(See page 110.)

Tandem-Mirror Ion Source

A tandem-mirror ion source uses electrostatic and magnetic fields to keep electrons in the ionization chamber and to assure a uniform output beam having low divergence in energy and angle. The improved ion source, which produces a beam of ions at any kinetic energy from 1 to 1,000 eV, could be useful in studies of the surface properties of materials, surface etching, deposition, and the development of plasma-diagnostic instrumentation.

(See page 63.)



Flexible Diaphragm Withstands Extreme Temperatures

Durable, simple, versatile, and relatively inexpensive to manufacture, a diaphragm seal retains flexibility throughout the temperature range of −200 to +600 °F (−129 to +316 °C). The diaphragm, which consists of a glass-fabric layer sandwiched between two silicone-rubber layers, should be suitable for refrigeration seals, autoclaves, storage lockers, and other sealing applications subjected to extreme temperature differentials.

(See page 122.)

Polyimide Film of Increased Tear Strength

A high-temperature linear aromatic polyimide with improved resistance to tearing is made by a new process that incorporates an elastomer into the polyimide. Linear aromatic condensation polyimides are materials of prime choice for use as films and coatings where durability at temperatures in the range of 200 to 300 °C is required. However, the tendency of these films to tear upon impact limits their usefulness in certain applications. It is anticipated that elastomer-containing polyimide film with improved toughness will prove useful for applications where resistance to tearing and long-term thermal stability are necessary.

(See page 85.)

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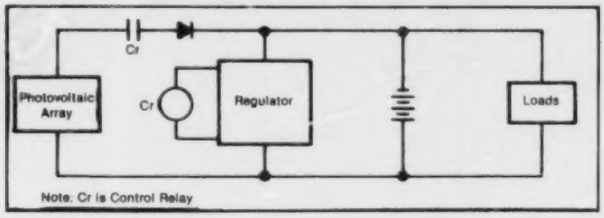
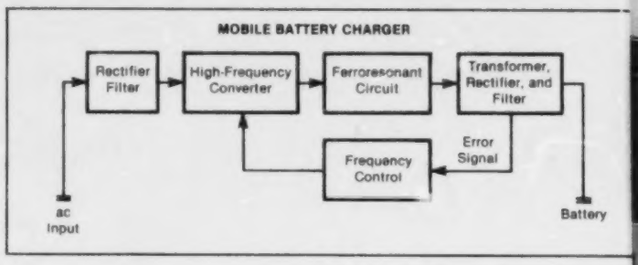




Voltage Regulators for Photovoltaic Systems

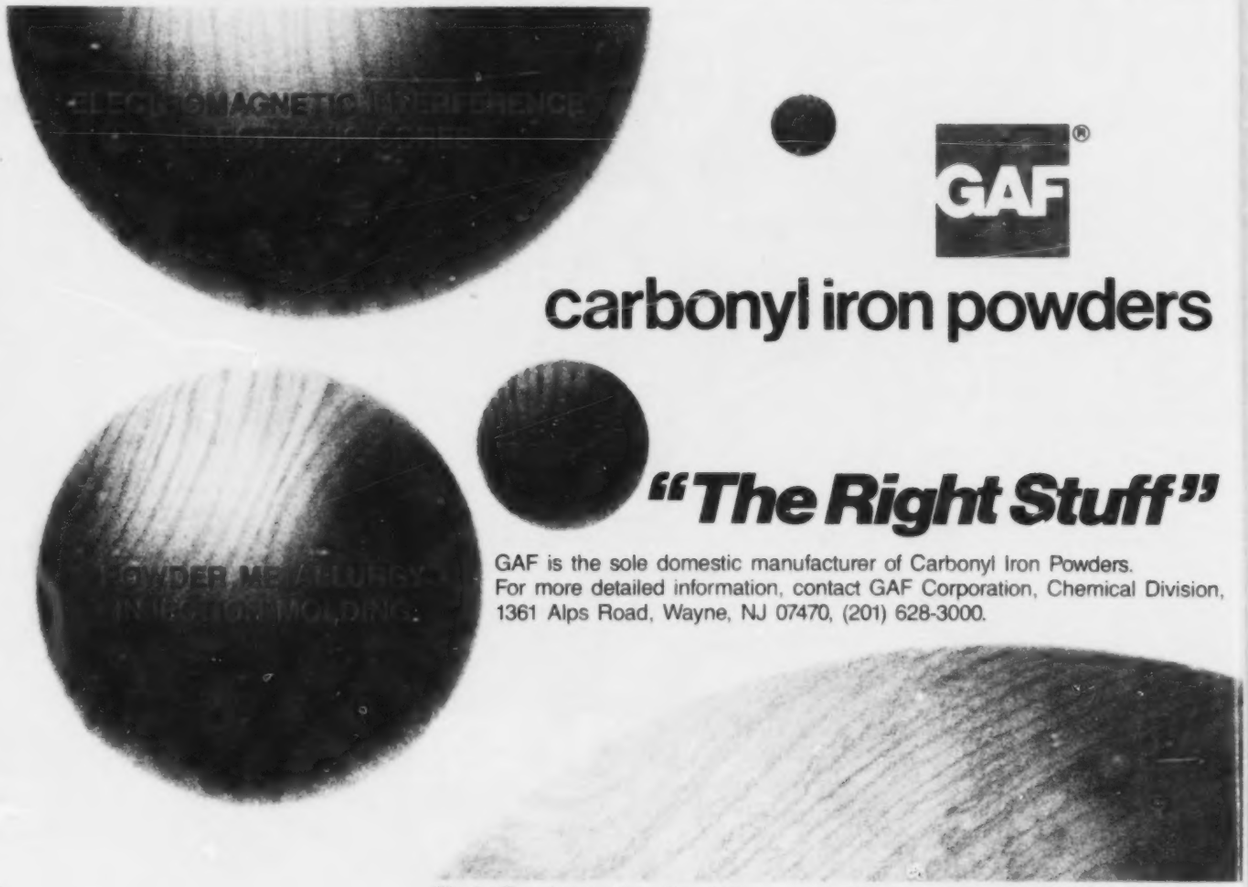
Two simple circuits were developed to provide voltage regulation for high-voltage (i.e., □75 volts) and low-voltage (i.e., • volts) photovoltaic/battery power systems. The use of these circuits results in a voltage regulator that is small, low-cost, and reliable, with very low power dissipation. The circuit shown in the figure is a regulator for high-voltage systems. It performs as an astable oscillator with a duty cycle derived from the system voltage. Adjustments in the nominal operating voltage are controlled by the potentiometer and by use of zener diodes of different voltage ratings. A light-emitting diode (LED) in the circuit provides a visual indication that the circuit is switching on and off. A single regulator may be used to control a small array, or several regulators may be used in parallel to control independent sections of a large array.

(See page 34.)

Ferroresonant Flux-Coupled Battery Charger

A portable battery charger operates at about 20kHz to take advantage of the relatively low weight and low acoustical noise of ferroresonant circuits operating in this frequency range. The charger can be split into a stationary unit connected to a powerline and a mobile unit connected to a battery or other load. Power would be transferred to the mobile unit by magnetic coupling between mating transformer halves. This is an advantage where sparking at an electrical connection might pose an explosion hazard or where the operator is disabled and cannot manipulate a plug into a wall outlet. Likely applications for the charger include wheelchairs and robots.

(See page 30.)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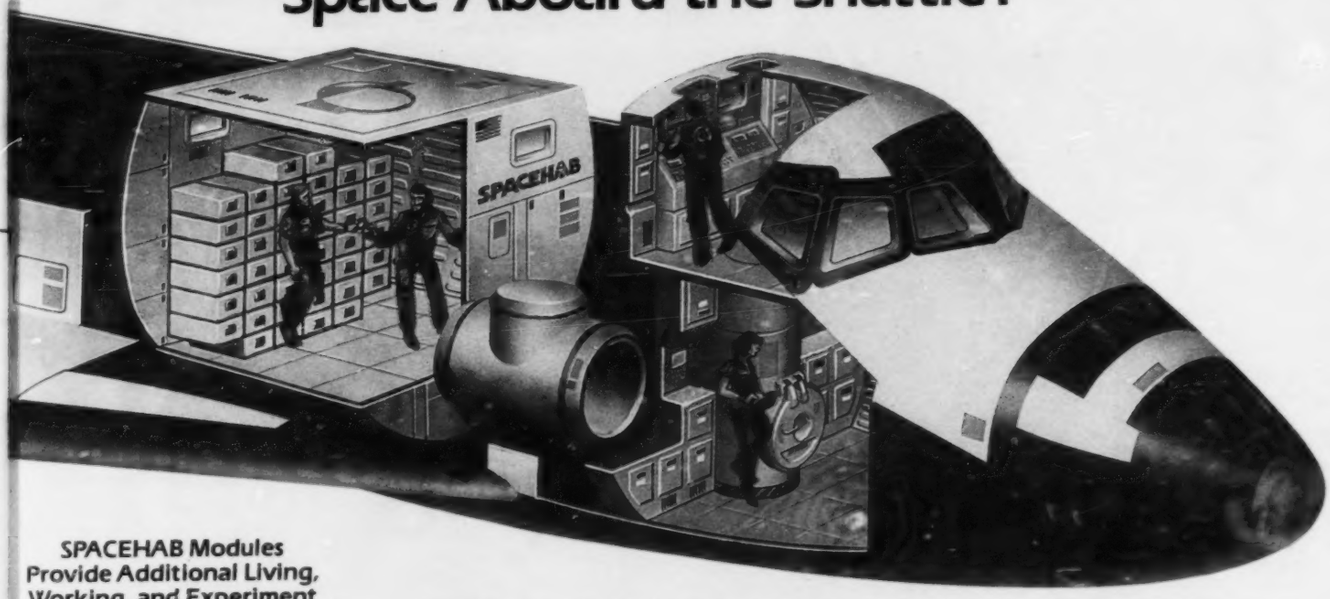

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SPACEHAB Modules Provide Additional Living, Working, and Experiment Space Aboard the Shuttle.

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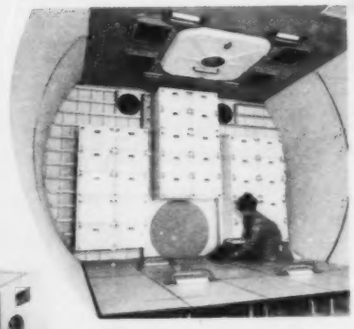
SPACEHAB Module interior configurations are highly flexible and easily modified due to the modularity of the design. They provide up to 64 additional middeck lockers for "man-tended" experiments. SPACEHAB will serve the requirements of NASA, the Department of Defense, commercial space experimenters and international users.

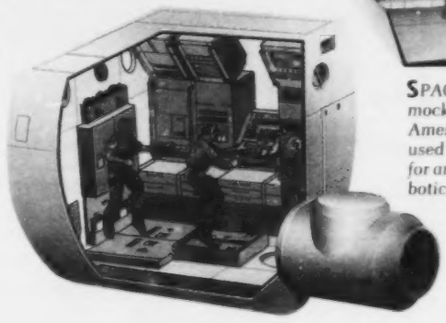
Simplified and Fast Payload Integration. Quick Response and Fast Turn-around.

The major design drivers for SPACEHAB Modules are:

1 Ease and speed of module integration into the orbiter,
2 Ease and speed of payload integration into the modules,
3 Economical use.

"Advanced" versions of SPACEHAB Modules with greater capabilities will be used for scientific, military and commercial research and development, as space station testbeds and simulation volumes, and for space station construction, logistics and operations support. Availability: 1991.





SPACEHAB Module full-scale mockup built for the NASA Ames Research Center is being used as a ground-based testbed for artificial intelligence and robotics research.

SPACEHAB Increases Orbiter Capability to Support Middeck Class Payloads at Low Cost.

SPACEHAB Modules offer scientific, military, and commercial microgravity and earth observation experimenters the opportunity to fly "man-tended" experiments at a reasonable cost.

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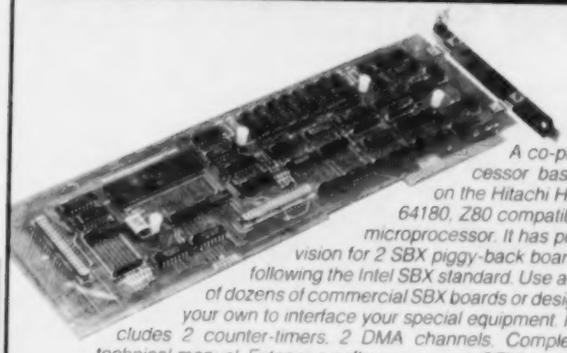
Circle Reader Action No. 347

HD64180 PC CO-PROCESSOR



A co-processor based on the Hitachi HD-64180, Z80 compatible microprocessor. It has provision for 2 SBX piggy-back boards following the Intel SBX standard. Use any of dozens of commercial SBX boards or design your own to interface your special equipment. Includes 2 counter-timers, 2 DMA channels. Complete technical manual. Extensive software support. OEM pricing. A general purpose auxiliary processor for IBM-PC or PC/AT. We have other co-processors, including units for VAX™ and PDP™-11, unibus™ or Q-bus. Call for more information.

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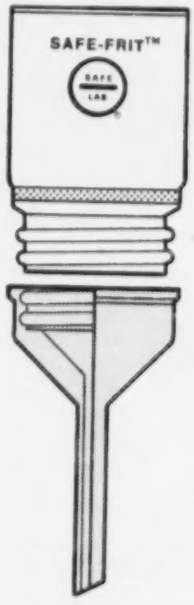

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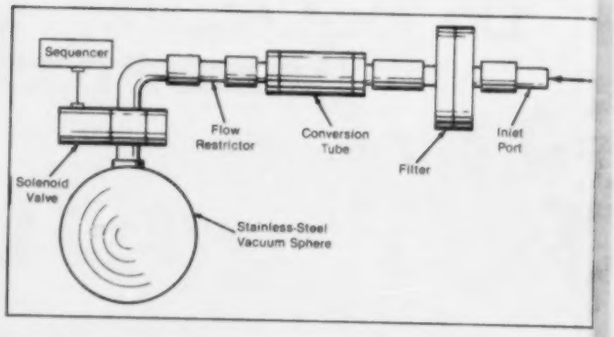
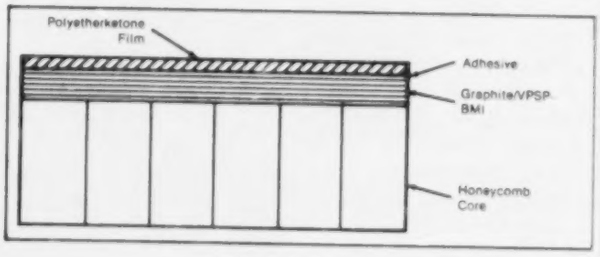


Batch Gas-Sampling System

A sampler collects a designated substance contained in the air and stabilizes it for later chemical analysis. The device can be used for concentrations ranging from a few parts per million to 100 percent. Activated by a sequencer, a solenoid valve opens, and gas from the surroundings is immediately drawn by the vacuum in a stainless-steel sphere into an inlet port, where particles are trapped in a filter. The gas continues into a conversion tube, where the component of interest reacts with the appropriate reagant and is changed into a stable compound in proportion to its concentration. At the end of a preset collection period or when the vacuum is exhausted, the sequencer closes the valve. The conversion tube, with its content, is then sent to a laboratory for analysis.

(See page 82.)



Lightweight, Fire-Resistant Graphite Composites

Aircraft safety could be improved with interior paneling made of a new laminate with good thermophysical properties. Featuring a lightweight graphite composite (graphite with a blend of vinyl polystyrylpyridine and bismaleimide, VPSP-BMI), the laminate resists heat and flame more effectively and produces much less smoke in fire than do the commonly used epoxy-resin-containing laminates. In addition, the new laminates have processing and curing parameters comparable to those of the epoxy/glass composites, making their manufacturing costs lower than those of such other high-temperature and fire-resistant resins as the polymides.

(See page 74.)

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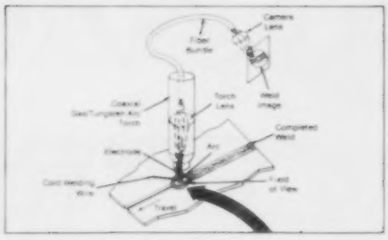
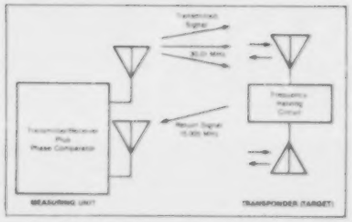


Robotic Vision for Welding

Protected within a welding-torch body, a lens and fiber-optic bundle give a robot a closeup view — along the axis of the welding electrode — of a weld in progress, without interfering with the workpiece or hindering tool movement. Relayed to a video camera on the robot manipulator frame, the detailed weld image is analyzed in real time by a control computer, which guides the robot and adjusts such parameters as the welding current and the feed of welding wire into the weld.

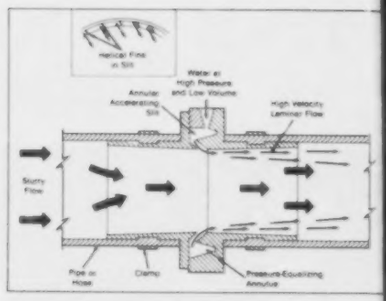
(See page 121.)



Transponder System for High-Frequency Ranging

A transponder system uses the phase difference between transmitted and reflected high-frequency radio waves to measure the distance to a target. To suppress spurious measurements of reflections from objects near the target at the transmitted frequency and its harmonics, the transponder at the target generates a return signal at half the transmitted frequency. The system should be useful in such applications as surveying, the docking of ships, and short-range navigation.

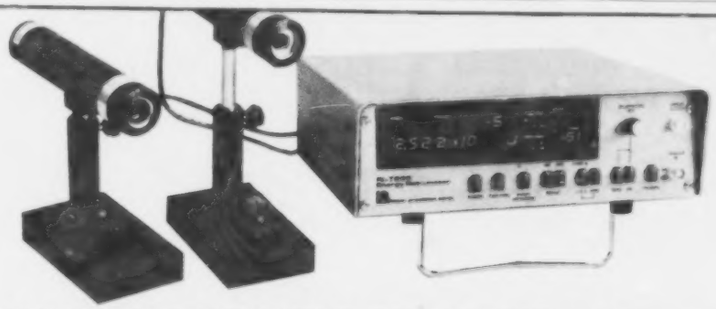
(See page 54.)



Flow Injector Would Keep Slurry From Settling

A proposed ring nozzle may help to prevent the choking of short-haul slurry pipelines. The ring nozzle helps to prevent blockages by enabling the injection of extra water or other fluid to increase the flow near the wall. A relatively small volume of water at high pressure is accelerated through an annular slit into the pipe (see figure), forming a laminar-flow boundary layer that entrains a large volume of slurry. Helical fins in the accelerating slit impart a rotation to the injected and entrained flows, thereby enhancing the ability to prevent settling of the slurry particles.

(See page 112.)



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Rjp-735	Cavity	1.0cm²	$1x10^{-7}$	$1x10^{6}$W/cm²	±½% (0.4-3μm); +½%, −4% (0.25-16 μm)
Rjp-736	Flat	20.0cm²	$1x10^{-4}$	$1x10^{3}$W/cm²	±3% (0.4-1μm); +3%, −9% (0.35-11 μm)
Rjp-765	Silicon	1.0cm²	$5x10^{-13}$	5W/cm²	0.3-1.1μm (not flat)

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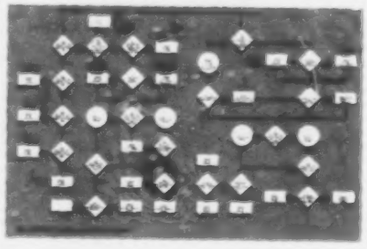

The easy way to select the right power meter, energy meter, radiometer, or detector to fit your requirements.

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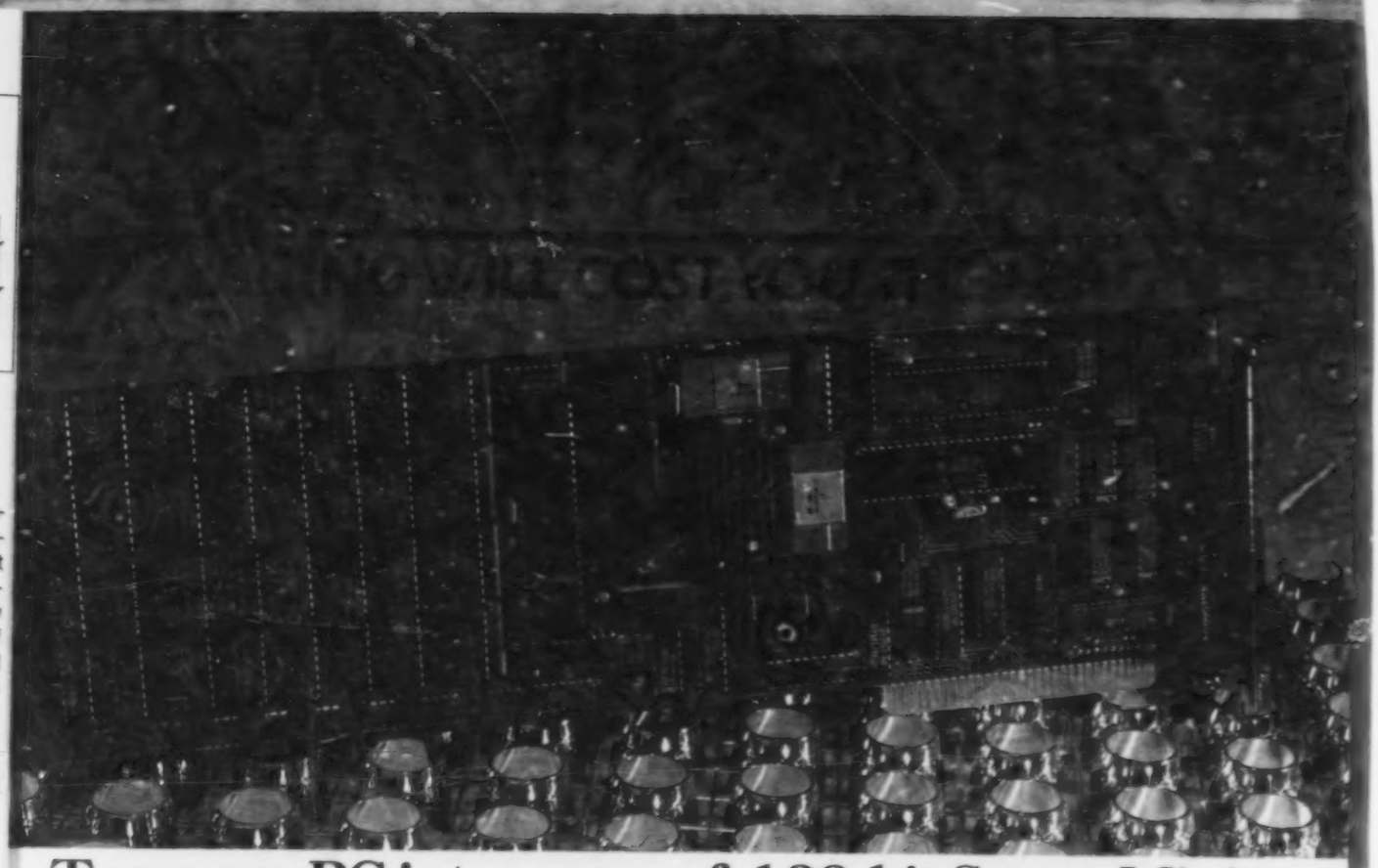

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Float Benchmark

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Unix Benchmarks

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Electronic Components & Circuits

Hardware, Techniques, and Processes

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34 **Voltage Regulators for Photovoltaic Systems**
35 **Pulling-Speed Control for Silicon-Web Growth**
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Ferroresonant Flux-Coupled Battery Charger

A high power frequency keeps design weight low.

NASA's Jet Propulsion Laboratory, Pasadena, California

A portable battery charger operates at about 20 kHz to take advantage of the relatively low weight and low acoustical noise of ferroresonant circuits operating in this frequency range. The charger can be split into a stationary unit connected to a powerline and a mobile unit connected to a battery or other load, as shown in Figure 1. Power would be transferred to the mobile unit by magnetic coupling between mating transformer halves. This is an advantage where sparking at an electrical connection might pose an explosion hazard or where the operator is disabled and cannot manipulate a plug into a wall outlet. Likely applications for the charger include wheelchairs and robots.

The circuit (see Figure 2) includes a series inductor in the tuned tank circuit of a ferroresonant saturating transformer. The series inductor allows the input voltage and power to vary over a wider range than is allowable with capacitor tuning alone, while keeping down the temperature rise of the saturating transformer.

The output voltage of the saturating transformer at a given frequency is hard limited to the value at the saturating flux. Since the transformer is operated in saturation, powerline voltage transients have little effect on the output. The output voltage is adjusted by varying the frequency, inasmuch as the output of a saturating transformer is approximately proportional to the frequency.

The output voltage is sampled by voltage divider R_1, R_2 and compared with a reference voltage representing the desired output. The resulting error voltage controls the output of a light-emitting diode in an optocoupler (which is used for electrical isolation). The optocoupler output is, in effect, a varying frequency-controlling resistance connected to the power-supply oscillator. The frequency is increased or decreased to decrease the size of the error voltage; that is, to bring the output voltage back toward the desired value whenever it has strayed due to a powerline voltage change or load change.

Toroidal transformer cores are used because they have the requisite high permeabilities and square hysteresis loops. For reliability and repeatable performance, the temperature rise of the core must be minimized. The cores are therefore mounted di-

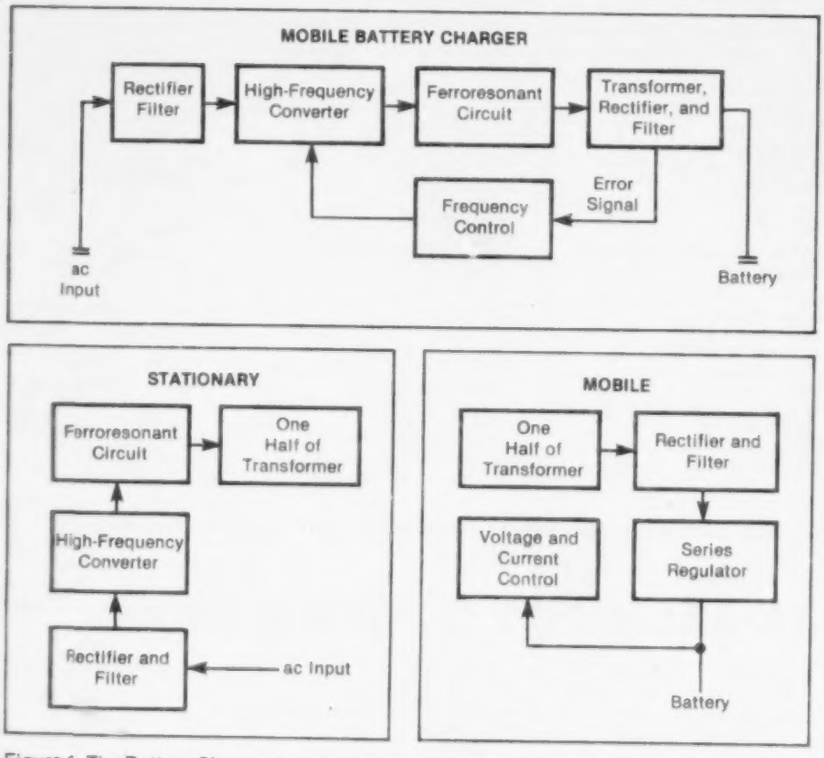

Figure 1. The **Battery Charger** could be built as a mobile unit or as a stationary unit plus a mobile unit that is brought to the stationary unit for charging.

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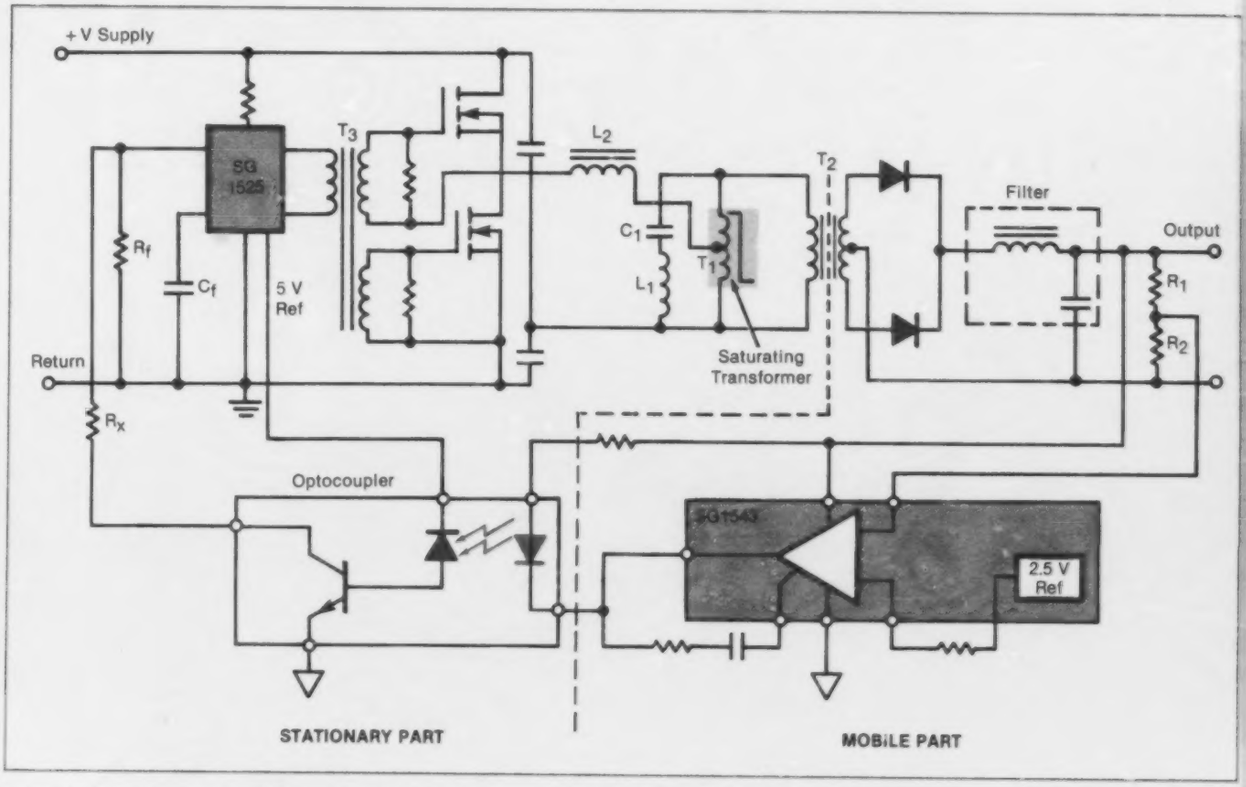

Figure 2. The **Charger Circuit** includes a lightweight ferroresonant saturating transformer. The circuit operates at about 20 kHz so that lightweight magnetic-coupling and output-filtering components can be used.

rectly in heat-sinking metal brackets that conduct heat away from cores and windings. Each winding surrounds its core and bracket. This kind of design ensures good heat sinking with reduced size and weight.

This work was done by Colonel W. T. McLyman of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 88 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 29]. Refer to NPO-16530.

GaAs Semi-Insulating Layer for a GaAs Device

Damaging thermal stresses at cryogenic temperatures would be greatly reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

In an improved design for a GaAs electronic device or integrated circuit designed to operate at cryogenic temperatures, the customary SiO_2 insulating layer is replaced by a semi-insulating layer of GaAs. The thermal expansions of the device and the covering layer therefore match closely, and thermal stresses caused by immersion in a cryogenic chamber are nearly eliminated.

Conventionally, a layer of doped SiO_2 in the form of borosilicate or phosphosilicate glass is deposited on the GaAs by pyrolytic deposition. Because of the difference in thermal expansion between the SiO_2 and the GaAs, severe thermal stresses are developed especially at the periphery of openings in the SiO_2 layer as the device is cooled from the deposition temperature or from room temperature to the operating temperature of 20 to 77 K. The interfacial stresses concentrate at the edges of the holes that are etched in the SiO_2 layer in the course of device fabrication, with consequent damage to the GaAs device.

In the new fabrication process, the semi-insulating layer of GaAs is grown epitaxially on the semiconducting GaAs of the device. The device is subsequently processed in a manner similar to that of the SiO_2. With negligible variations caused by doping, the crystal lattice and thermal expansion of the two GaAs layers match closely at all temperatures.

The electrical resistivity of the semi-insulating GaAs (10^{12} ohm-cm) is not as great as that of SiO_2 (10^{17} ohm-cm), but apparently it is sufficient for the intended application. Chromium doping might increase the resistivity. In devices that have to operate at high frequency, a more serious disadvantage lies in the fact that the dielectric constant of the semi-insulating GaAs is 12, while that of SiO_2 is only 3.8. The relatively high dielectric constant will give rise to higher shunt displacement-current leakage.

This work was done by Greg Sherrill and Robert J. Mattauch of the University of Virginia for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 80 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office — JPL [see page 29]. Refer to NPO-16394.

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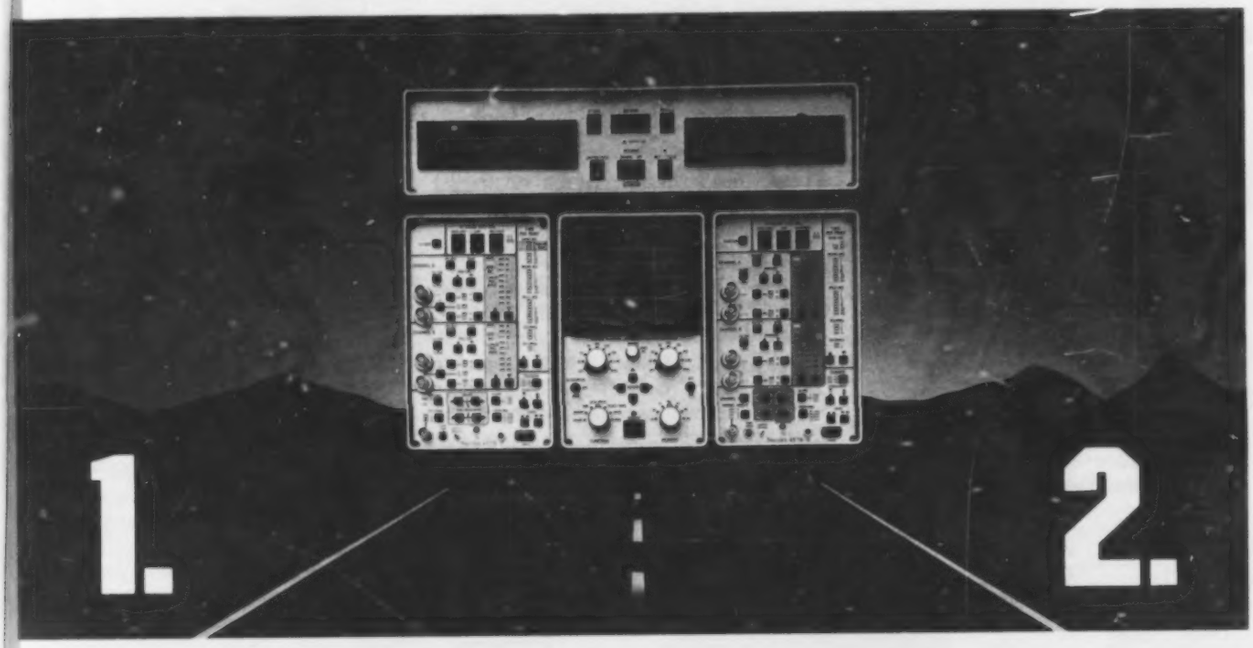
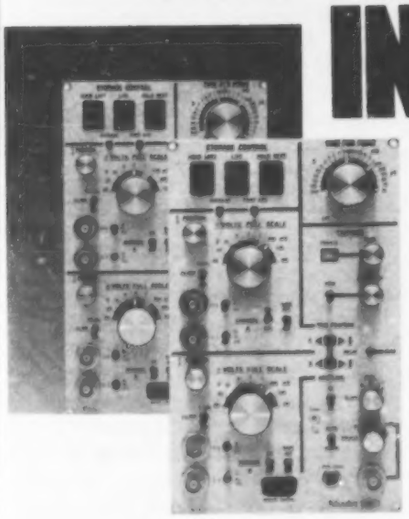


TWO DIGITAL SCOPES IN ONE.



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Circle Reader Action No. 438

Voltage Regulators for Photovoltaic Systems

Two small, inexpensive regulator circuits consume little power.

Lewis Research Center, Cleveland, Ohio

Two simple circuits were developed to provide voltage regulation for high-voltage (i.e., >75 volts) and low-voltage (i.e., <36 volts) photovoltaic/battery power systems. The use of these circuits results in a voltage regulator that is small, low-cost, and reliable, with very low power dissipation.

A simple oscillator circuit can control photovoltaic-array current to regulate system voltage and control battery charging. The circuit senses the battery (and system) voltage and adjusts the array current to keep the battery voltage from exceeding a maximum voltage (determined by the number and type of battery cells). The oscillator circuit combined with a power-control device forms a complete regulator (see top parts of Figures 1 and 2).

The regulator switches the photovoltaic array on and off at a rate inversely proportional to the battery voltage. If the battery voltage is lower than the low voltage limit, the circuit turns on the array full time. If the battery voltage is above the high voltage limit, the circuit turns off the array. The circuit switches the array on and off periodically if the battery voltage is between these two voltage limits. The duty cycle (ratio of the time on to the times on plus off) of this switching action is varied, according to the battery (system) voltage, to vary the average array current. This action then keeps the battery voltage at or below the high voltage limit.

The circuit shown in Figure 1 is used for high-voltage systems (i.e., >75 volts). The oscillator circuit incorporates an oscillator/timer integrated circuit IC_1, type 555. With the external components, the circuit is configured as an astable oscillator with a period of approximately 5 seconds. The duty cycle of the output is controlled by the voltage at pin 5 of IC_1, which is derived from the system voltage.

The nominal operating voltage of the circuit can be changed in two ways. For large-scale adjustments (>3 percent), the zener diodes can be replaced with those having different voltage ratings. For finer adjustments and calibrations, the 2-kilohm potentiometer can be adjusted. With the two 60-volt zener diodes in Figure 2, this regulator is used in a 120-volt dc (nominal) system.

The circuit shown in Figure 2 is used for low-voltage systems (i.e., <36 volts). The oscillator circuit incorporates a commercial pulse-width-modulated switching circuit, type ZN1066, IC_2. IC_2 consists of (along with other functional elments) a comparator and an oscillator. The output of IC_2 is a 0.5-Hz switching waveform, with the duty cycle of the waveform being a linear function of the system voltage. The nominal operating voltage of the circuit can be changed in two ways. For major changes in voltage range, such as for operation at 6, 12, or 24 volts, several component values need to be changed. For small adjustments such as calibrations, the potentiometer is adjusted.

A light-emitting diode (LED) in each circuit provides a visual indication that the circuit is switching on and off. A single high- or low-voltage regulator may be used to control a small array (see Figure 1), or several regulators may be used in parallel to control independent sections of a large array. The high-voltage system can utilize multiple high-voltage regulators: Multiple regulators tend to smooth the total array current to minimize the effects of switching transients. For higher power applications, the power-switch section may be replaced with a circuit of higher power capabilities, or it may be used to control a larger relay or transistor.

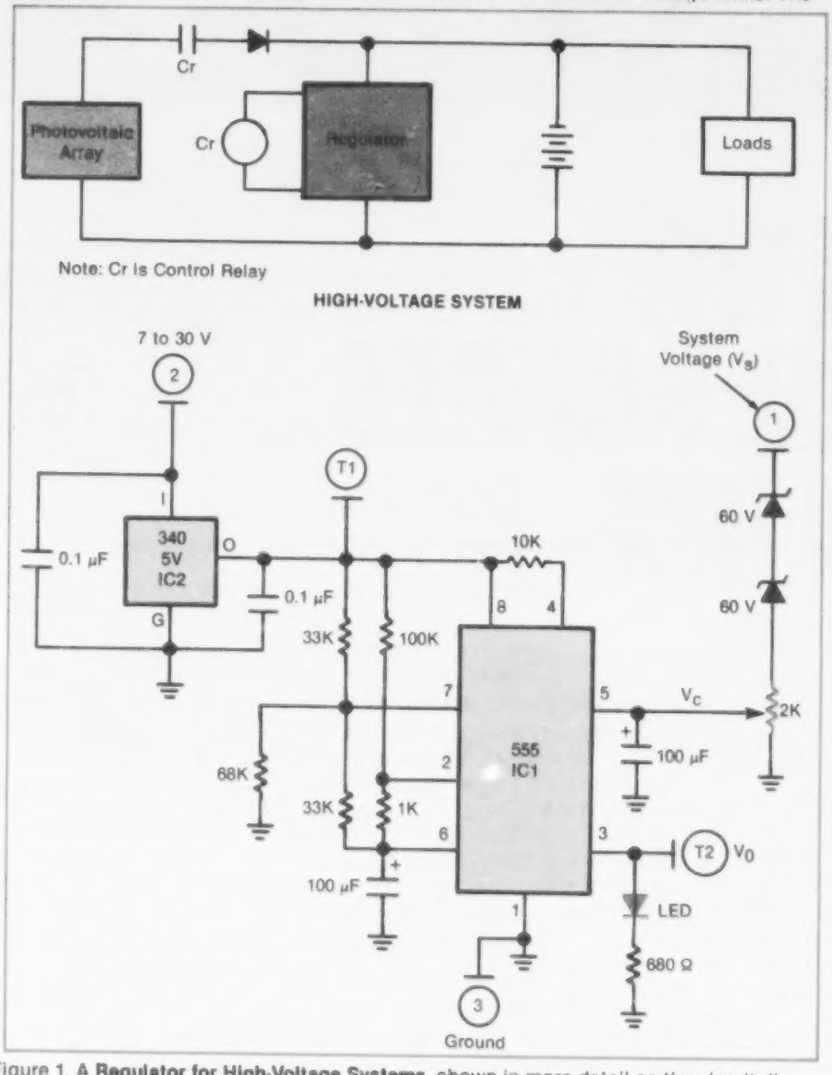
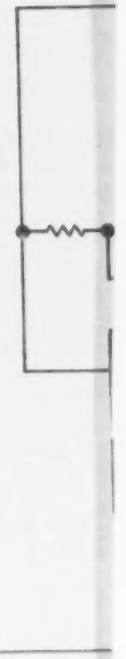


Figure 1. A **Regulator for High-Voltage Systems,** shown in more detail on the circuit diagram, performs as an astable oscillator. Its duty cycle is derived from the system voltage. Adjustments in the nominal operating voltage are controlled by the potentiometer and by use of zener diodes with different voltage ratings.



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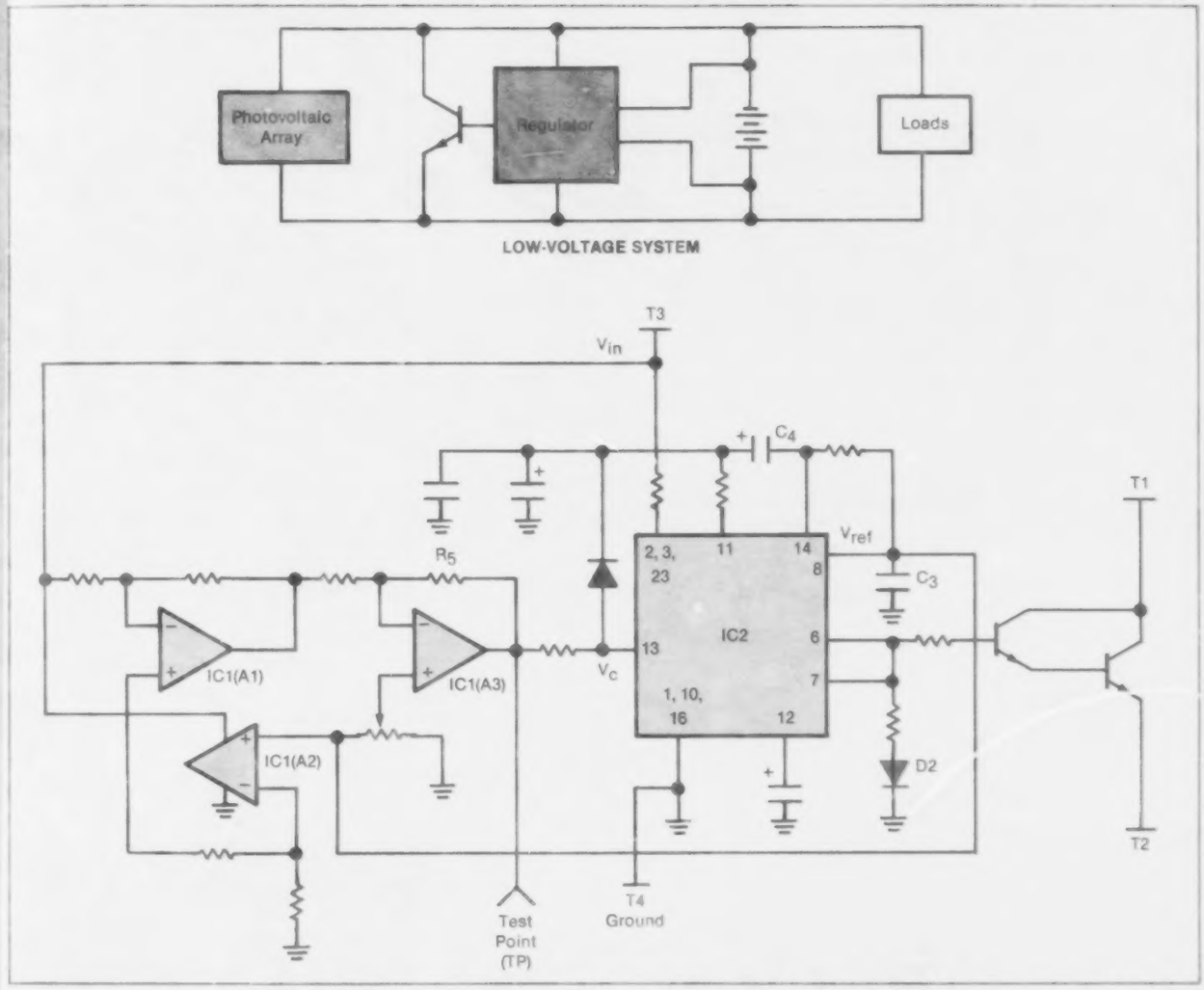


Figure 2. A **Regulator for Low-Voltage Systems,** shown in more detail on the circuit diagram, uses a commercial switching circuit as an oscillator. Small adjustments in the nominal operating voltage are controlled by the potentiometer; larger adjustments require changes in values of several components.

This work was done by Richard DeLombard of **Lewis Research Center.** *Further information may be found in NASA TM-83625 [N84-25926/NSP], "Low Frequency Switching Voltage Regulators for Terrestrial Photovoltaic Systems."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LEW-13288

Pulling-Speed Control for Silicon-Web Growth

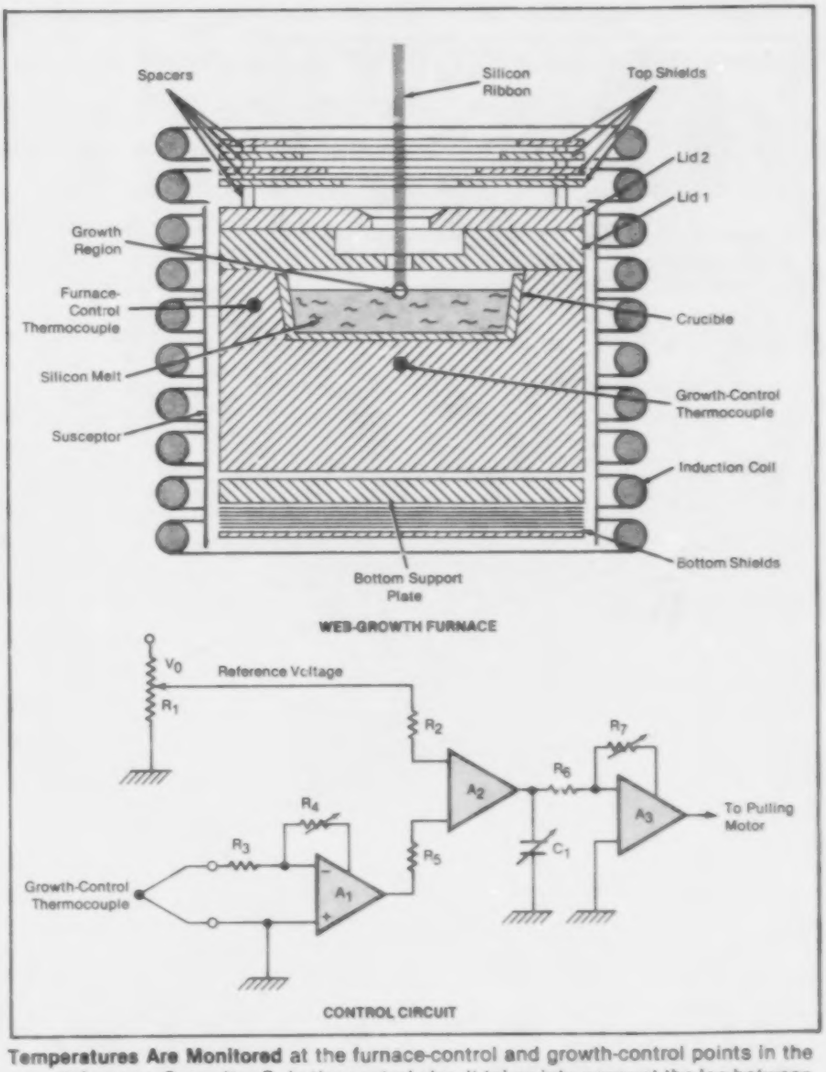
An automatic system promises to ensure high-quality silicon ribbon.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed control system for the dendritic-web growth of silicon ribbons varies the ribbon speed according to the melt temperature. The system would prevent too fast or too slow withdrawal of the silicon web, which can cause pullout of the web or excessive web thickness, respectively. The system would also enable the semiautomatic startup of web growth by automatically increasing the web speed from zero to the optimum value.

A growth-control thermocouple is placed at a predetermined point (see figure) within the growth furnace but outside the crucible. The measured temperature determines ahead of time the temperature at the growing crystal. By a combination of prior temperature measurements and thermal modeling of the furnace, the relationship between the growth-control-thermocouple temperature and the crystal-growth-zone temperature is established and expressed as a time constant for exponential transient damping. Typically, the time constant is of the order of 2 minutes.

A single-crystal seed of silicon is inserted in the melt, as in the usual procedure, and the temperature of the melt is decreased so that the seed crystal grows outward. When the seed reaches a predetermined size, the system starts the motor to withdraw the seed, pulling with it a thin web of silicon. The system adjusts the motor speed continuously as the



Temperatures Are Monitored at the furnace-control and growth-control points in the growth furnace. Capacitor C_1 in the control circuit takes into account the lag between a temperature change at the growth-control point and a temperature change at the site of the growing ribbon.

monitored temperature varies. This adjustment allows for the dip in melt temperature necessary to start the growth as well as for temperature variations during the subsequent growth.

As shown in the figure, the output of the growth-control thermocouple is amplified and inverted by operational amplifier A_1. The output of A_1 and a reference voltage are fed to differential amplifier A_2. The differential output of A_2 is fed to a final amplifier, A_3 that provides the control signal for the pulling motor.

When the surface of the melt is at the starting temperature (the melting point of silicon), the reference voltage is adjusted to produce a zero voltage from A_2 and thus also from A_3. The motor speed is thus initially set at zero.

The furnace control is then reset to a slightly lower temperature. When the temperature change reaches the growth-control thermocouple, the output of this thermocouple decreases, causing the output of A_1 to increase. The output of A_2 increases at a rate determined by the size of capacitor C_1, which takes into account the lag in the temperature drop in the web-growth region. The control signal from A_3 thus reflects the lag, gradually increasing the motor speed in accordance with the estimated current temperature at the growth front.

This work was done by Robert Richter of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 105 on the TSP Request Card.*
NPO-16685

Long-Term Electronic Timer

Power is turned on for intervals up to months.

Ames Research Center, Moffett Field, California

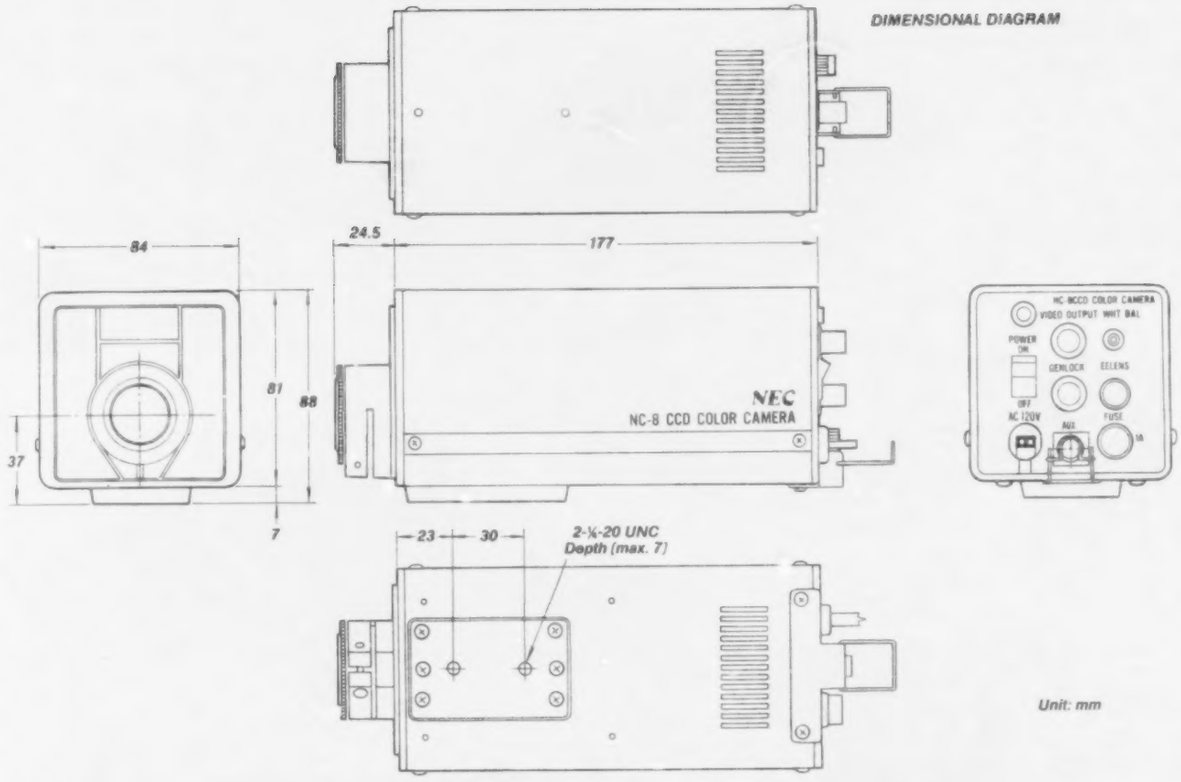
A timing circuit turns on a power source upon command, then turns it off again after a preset interval. In comparison with prior devices, the unit consumes little power and is smaller, lighter in weight, and less complicated.

The timer includes an oscillator and a counter in an integrated circuit (see figure). The timing interval equals the oscillator period multiplied by the number of cycles to be counted. The oscillator frequency depends upon resistor R_s and capacitor C_x. The number of oscillator cycles to be counted before the counter output changes state is determined by the selection of the counter output terminal, shown here as pin 3. The interval can be set anywhere in the range from fractions of a second to months; it is given by $T = 0.55R_sC_x2^n$, where n is an integer determined by the counter-output selection. Accuracy can be improved with a crystal.

Operation is initiated by the closure of momentary switch S_1 (or by a command signal having a similar effect). This grounds one side of relay K_1, thereby activating the relay and causing the closure of the switches that supply power to the timer and to the load. The turn-on of V_{cc} at the timer is coupled through C_1 to the counter-reset terminal, thus resetting the counter. The initial reset voltage transient is then drained away through R_1 to permit normal operation.

During the first half cycle of the counter operation, the counter output voltage (at pin 3 in this case) is low. This turns on transistor Q_1 so that relay K_1 latches on, enabling the timer to continue running even though switch S_1 has opened.

The oscillator runs while the relay is on. When the number of oscillator cycles reaches the limit, the counter output voltage at pin 3 goes high. This turns off Q_1



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Sensitivity	1,600 Lux F4.0
Minimum illumination	10 Lux F1.4 AGC: ON (20% signal output level)
White balance adjustment	Manual/Remote
Lens mount	C-Mount
Power consumption	Approx. 6.5W (less than 9VA)
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For more information about the NC-8, TI-22AII, TI-22PII and TI-26A industrial cameras, contact the Industrial Video Group, Broadcast Equipment Division, NEC America, Inc., 1255 Michael Drive, Wood Dale, IL 60191 Toll free 1-800-323-6656. In Illinois phone 312/860-7600.

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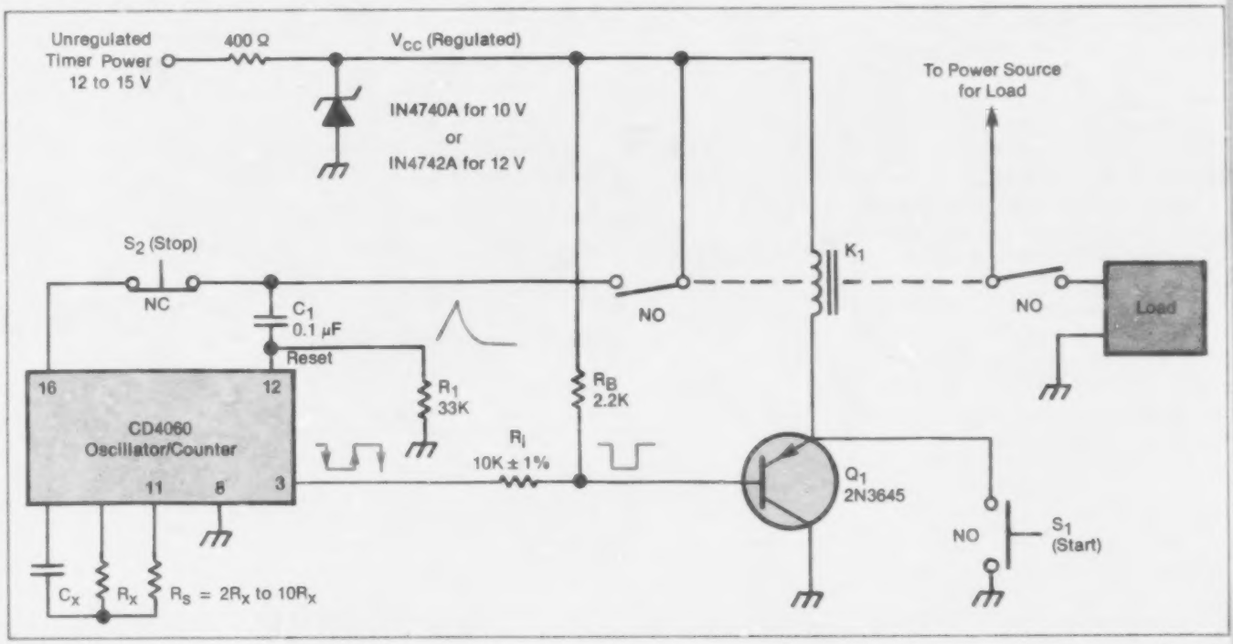


An **Oscillator and a Counter** in an integrated circuit package are combined with other commercially available parts to form a simple, reliable timing circuit. The timer is precise within 0.08 percent.

thereby turning off the relay and returning the system to the original "power-off" state to await the next starting command. The timing cycle can also be interrupted and the system turned off by opening normally-closed switch S_2.

This work was done by Gerald Temple and Tom Kalaskey of **Ames Research Center**. *For further information, Circle 1 on the TSP Request Card.*

inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11590.

Electroabsorption Infrared Modulators

Compact monolithic arrays will operate at high speed.

NASA's Jet Propulsion Laboratory, Pasadena, California

New solid-state infrared modulator arrays have been fabricated and tested successfully. The arrays are based on electroabsorption, and because of the high speed inherent in small devices of this kind, they are expected to perform well at multigigahertz frequencies in such applications as multiplexing, demultiplexing, high-speed recording, and printing.

The modulator array includes eight parallel single-mode waveguides. Each waveguide is also a p-π-n heterojunction diode. To modulate the light in a waveguide/diode, a reverse voltage is applied at the diode contacts. Most of the applied voltage is developed across the π region, which is also the region of highest refractive index and, therefore, the region in which most of the optical radiation is guided. Thus, most of the radiation travels through the high-electric-field region, resulting in the optimum electroabsorption interaction.

Molecular-beam epitaxy is used to grow three $Ga_xAl_{1-x}As$ layers on an n+—GaAs substrate (see Figure 1). Next, groups of eight 5-μm-wide CrAu contact stripes with center-to-center spacing of 9 μm are depos-

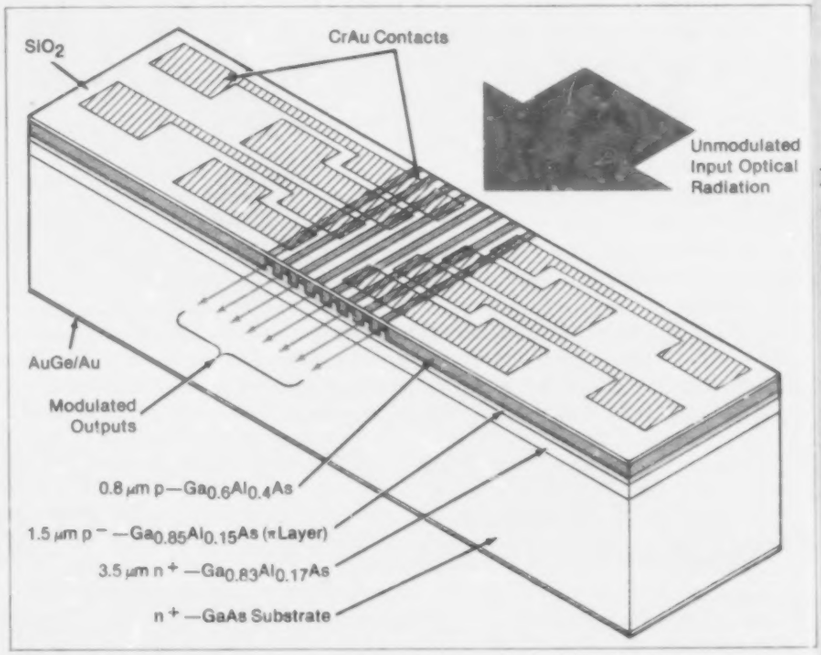
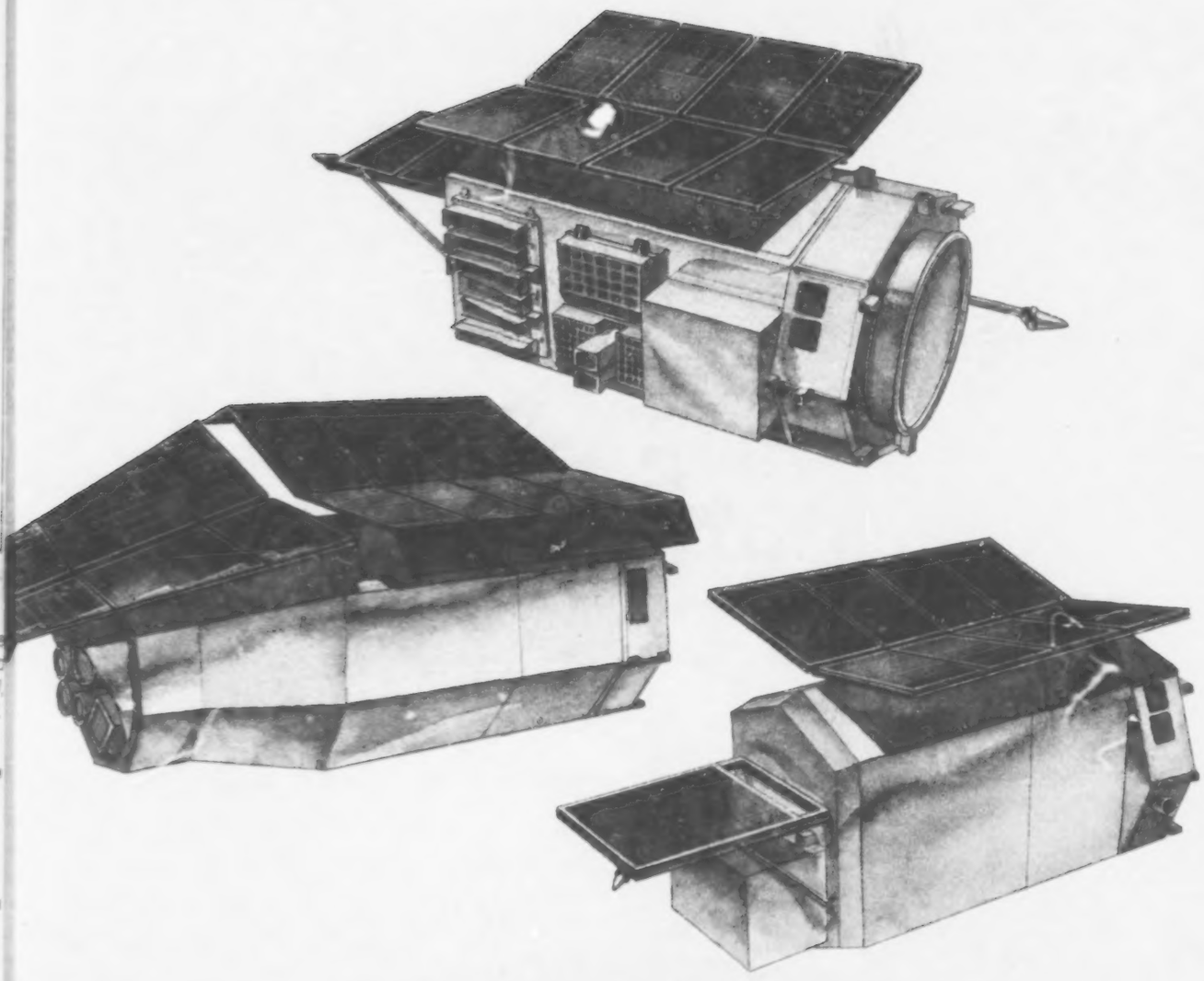


Figure 1. A **Monolithic Array of Modulating Waveguides** is fabricated in $Ga_xAl_{1-x}As$.



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CONTROL DATA

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ited using a lift-off technique.

The waveguides are electrically and optically isolated from each other by proton implantation. Thick photoresist stripes on top of the CrAu stripes serve as the implantation mask. The proton energy is 160 keV, and the dose is 3×10^{15} cm^{-2}.

A film of SiO_2 is deposited, and contact holes are opened by standard photolithographic techniques. The second level of CrAu contacts is then evaporated onto the SiO_2. Finally, the wafer is lapped, a contact layer of AuGe/Au is evaporated onto the bottom, and the wafer is cleaved into individual devices.

In tests, arrays were illuminated by a beam focused from a semiconductor laser (wavelength 830 to 850 nm) on the entrance facets of the waveguides. When reverse bias was applied to individual waveguides, the outputs of those waveguides were reduced by electroabsorption (see Figure 2).

The magnitude of electroabsorption increases nonlinearly with voltage, becoming noticeable at higher levels (typically, 35 V for nearly complete extinction). The magnitude of electroabsorption also depends on the wavelength and polarization: It is higher in the TE than in the TM mode, and higher at 830 nm than at 850 nm.

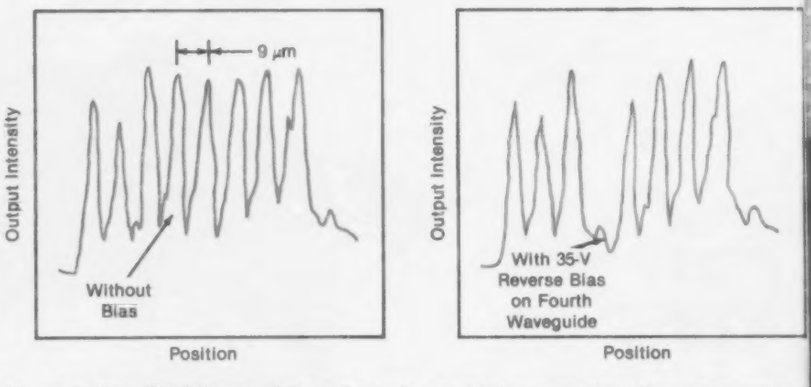


Figure 2. **Near-Field Scans** of the output of a modulator array show the suppression of output of the fourth waveguide from the left when 35-V reverse bias is applied to it. Residual electrical coupling with the fifth waveguide causes a slight diminution in the output of that unit as well. This defect should be curable in future devices by deeper ion implantation during manufacturing.

This work was done by Deborah L. Robinson, William K. Marshall, and Joseph Katz of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 48 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 29]. Refer to NPO-16481.

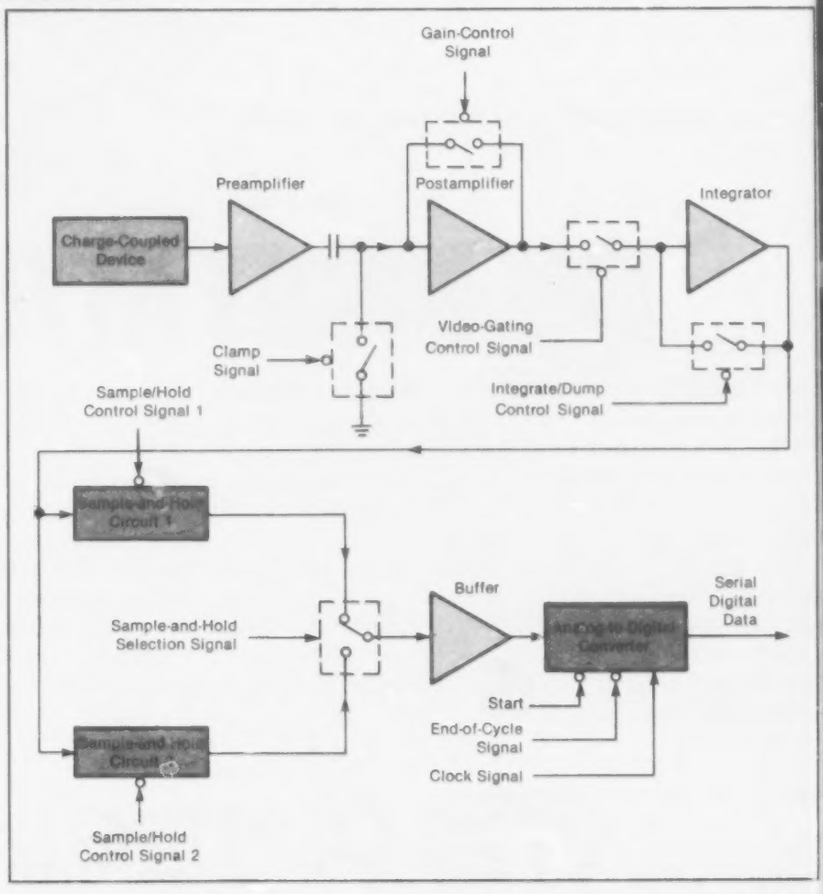
Dual-Sampler Processor Digitizes CCD Output

Less bandwidth is required for processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

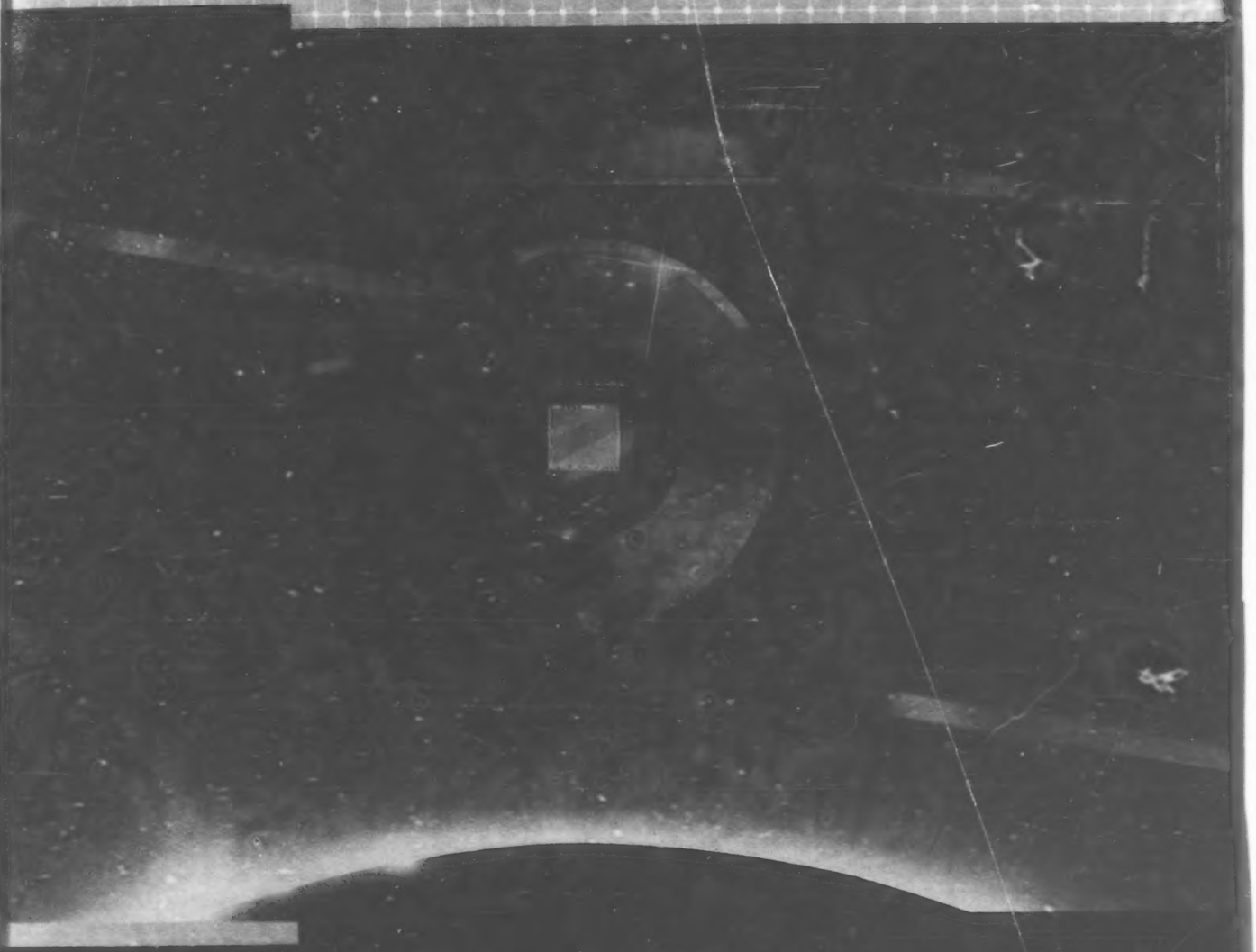
A proposed circuit (see figure) for processing the output of a charge-coupled device (CCD) imager provides increased time for analog-to-digital conversion, thereby reducing the bandwidth required for video processing. Instead of the one sample-and-hold circuit of a conventional processor, the improved processor includes two sample-and-hold circuits that are alternated with each other.

To process a CCD signal in real time, the output of each pixel on the imager must be sampled, held, and converted to digital values during one pixel period — typically about 15 μs. A sample-and-hold circuit requires about 5 μs to acquire a sample with 0.01 percent accuracy, leaving only about 10 μs for analog-to-digital conversion. For some converters, this is not enough time. The new circuit makes more time available by



The **Dual-Sampler Processor** operates with lower bandwidth and with timing requirements less stringent than those of a single-sample processor.

Sensing the future.



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Red Horizon (1981), acrylic on canvas, 10' x 6'. Norman Zammitt. In mixing and preparing colors for a painting, the artist uses computer generated logarithmic progressions, a kind of electronic palette. These mathematical sequences help determine the exact relationships of individual colors that collectively achieve a "blend." Following these calculations, he weighs precise amounts of color together on a gram scale. Five colors are used to create a total of forty-eight differentiated colors. After they are mixed and painted in order, they represent a harmony of extremes: of light and gravity.

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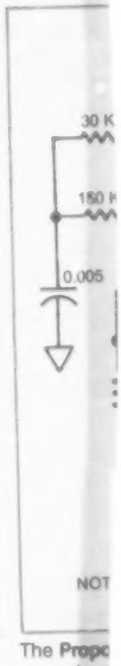

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assigning part of the task to each of two sample-and-hold circuits: This allows a slower converter to be used, and each sample-and-hold circuit can be operated in a track-and-hold mode for additional accuracy of signal acquisition.

During a pixel interval, one sample-and-hold circuit samples while the other holds and provides input to the analog-to-digital converter. During the next pixel interval, the sample-and-hold circuits exchange roles. Each sample-and-hold circuit thereby prolongs the holding period beyond the pixel-sampling interval, well into the next pixel interval.

In the proposed design, the sampling interval is approximately 7 μs and the holding period approximately 23 μs. The time available for analog-to-digital conversion would be increased to approximately 12 μs, with a concomitant decrease in the required analog bandwidth and reduction of noise. An additional advantage is gained by the relaxation of speed and timing requirements of the clocking and signal-processing elements. Disadvantages include the increased complexity associated with the additional sample-and-hold circuit; the requirement of a single-pole, double-throw video switch with sufficient isolation between the sample-and-hold units; and an additional output delay of one pixel interval.

This work was done by Phil M. Salomon of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 45 on the TSP Request Card.*
NPO-16726

Pulse-Width Proportional-Controller Circuit

A quad operational amplifier circuit yields full 0- to 100-percent pulse-width control.

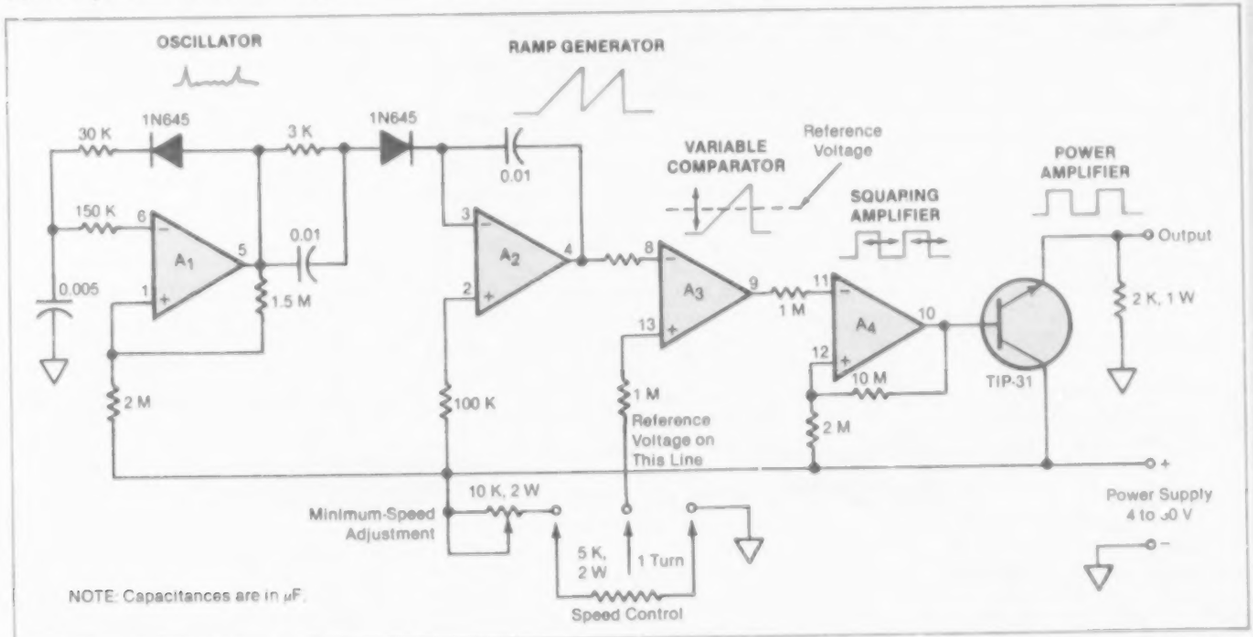
Marshall Space Flight Center, Alabama

A proportional controller for motor speed provides full 0- to 100-percent linear control of the durations of motor-driving pulses. Conventional proportional controllers using phase-shift techniques provide a more-limited pulse-width range, typically 15 to 85 percent. As with any pulse-width proportional controller, the motor has high starting torque because the pulse height always equals the full supply voltage.

The controller (see figure) uses a commercially available LM3900 integrated circuit, which requires only a single supply voltage of 4 to 30 V. The pulse-repetition rate is set by a 1-kHz oscillator that incorporates amplifier A_1. The oscillator feeds ramp generator A_2, which generates a linear ramp voltage for each oscillator pulse. The ramp signal feeds the inverting input of comparator A_3; the speed-control voltage feeds the noninverting input.

Thus, the output of the comparator is a 1-kHz pulse train, the pulse width of which changes linearly with the control voltage. The control voltage can be provided by an adjustable potentiometer (as shown) or by an external source of feedback information such as a motor-speed sensing circuit. Depending on the control-voltage setting, the pulse duration can be set at any value from zero (for zero average dc voltage applied to the motor) to the full pulse-repetition period (for applied motor voltage equal to dc power-supply voltage).

An amplifier stage (A_4) with a gain of 10 acts as a pulse-squaring circuit. A TIP-31 medium-power transistor is driven by A_4 and serves as a separate power-amplifier stage. Additional power amplification may be required, depending on the motor being controlled. Since the power transistors that drive the motor are used essentially



The **Proportional Controller** is constructed using an integrated circuit containing four operational amplifiers. A separate power-amplifier stage is also included.

as switches, transistor power dissipation is minimized. Thus the controller could also be used for the efficient control of such resistive loads as heaters.

This work was done by Rodney W. Clukey of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 10 on the TSP Request Card.* *MFS-29102*

A Combined Scanning Configuration for Near-Field Antenna Measurements

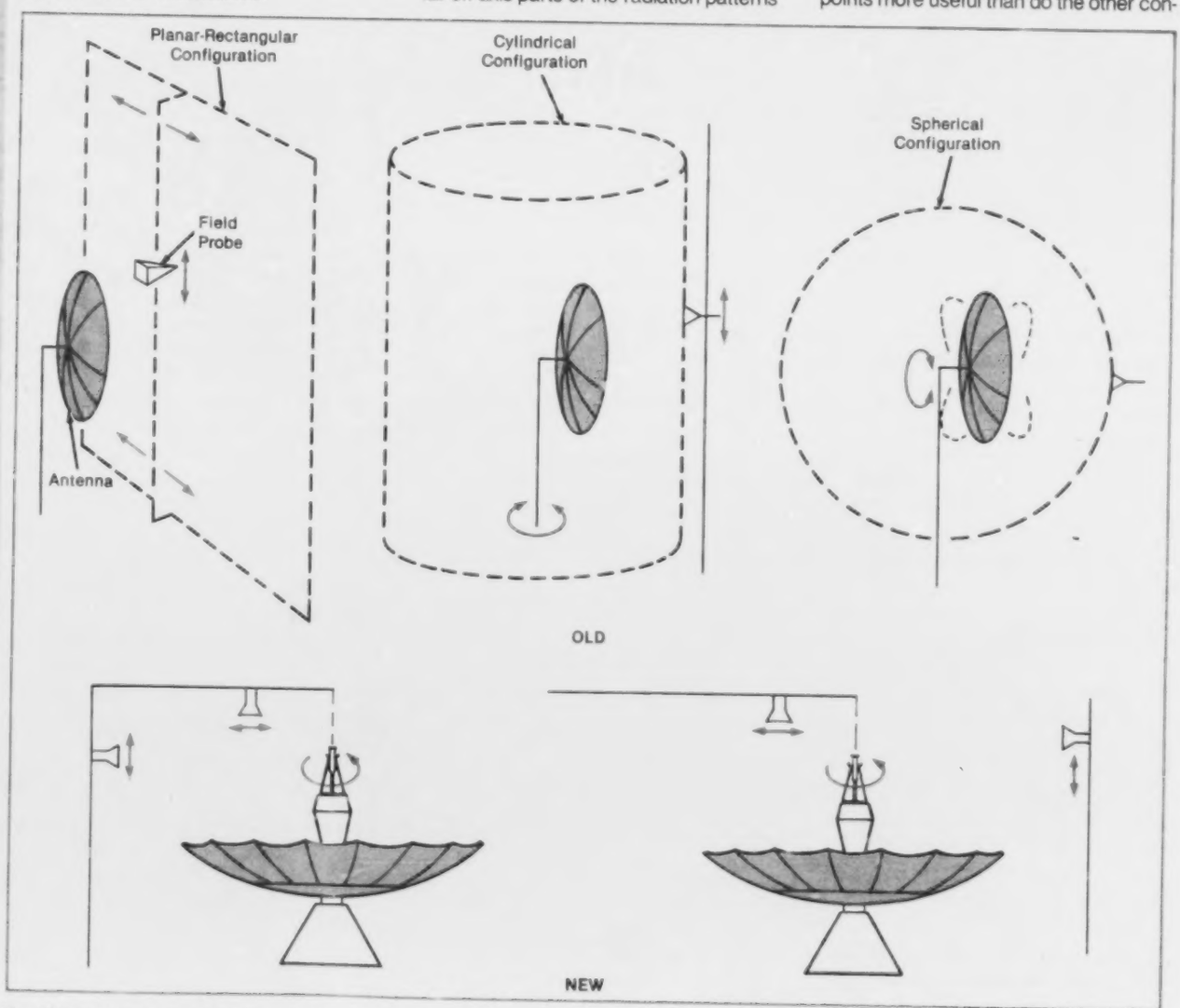
Combination of a cylinder and a plane enhances the customary configurations

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed scanning configuration for near-field antenna measurements uses cylindrical and plane-polar coordinate surfaces to guide the motions of the electromagnetic-field probes. Near-field measurements are needed especially to enable the determination of the far fields of large, low-sidelobe, multiple-beam antennas, for which the application of far-field measurements are often not suitable.

Prior near-field measurement coordinates were laid out on hemispherical, planar, or cylindrical surfaces (see top of figure). However, none of these configurations is suitable for measurements on large, multiple-beam antennas that may be sensitive to the orientation in the gravitational field: It is difficult to move the probes over such large surfaces, and the far-off-axis parts of the radiation patterns cannot be measured, even though they may contain important information on sidelobes.

The improved scanning arrangement (see bottom of figure) includes a vertical cylindrical coordinate surface topped by a horizontal plane-polar coordinate surface. This configuration surrounds the antenna with a pattern of measurement points more useful than do the other con-



The **Old and New Scanning Configurations** differ in size and shape. The proposed new cylindrical/plane-polar scanning configuration requires less space, yet is expected to give complete measurements with fewer mechanical complications.

figurations. The overall dimensions of the vertical and horizontal scanning arms depend on the size of the antenna under test. However, this configuration lends itself to a modular mechanical design that can be adapted easily to antennas of different sizes and shapes.

Other advantages of the new configuration include the following:

- Reflector-dish and other antennas that are sensitive to gravitation can be pointed skyward to balance the weight.
- The scanning motions are simple; the antenna can be rotated on a stand, and each probe has to be moved only on a straight track. Alternatively, the probe tracks can be rotated about the antenna on a large stand.
- The plane-polar and cylindrical patterns can be scanned separately or together.
- Far-field patterns can be inferred from near-field measurements even for large beams that are scanned substantially away from the antenna axes. Both reflector antennas and arrays of radiating elements can be tested.
- It is not necessary to extend the planar area much beyond the projected antenna aperture because the cylindrical surface can be used to obtain the rest of the required near-field, large-angle data that would otherwise have to be obtained on the outer part of the plane. Thus, the planar-surface area required to test a large antenna is smaller than in a planar (only) configuration.
- With modifications of the computer programs for processing planar-polar and cylindrical measurements, a combined computer program can be generated.

This work was done by Yahya Rahmat-Samii of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 126 on the TSP Request Card.*
NPO-16644

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Antenna Quadripod With Reduced Blockage

The net reflector gain is increased by 0.32 dB.

A design study for the subreflector support of a 64-m-diameter paraboloidal microwave antenna is described in a 19-page report. The objective of the study was to upgrade an existing antenna quadripod, subject to mechanical and electromagnetic design requirements and optimization criteria. The principal effort was directed toward reducing the signal blockage by the quadripod legs while minimizing structural weight.

The improved quadripod had to do the following:

- Support a larger, heavier subreflector at the quadripod apex;
- Accommodate lifting loads of the feed-cone and subreflector hoists;
- Be stiff enough so that its vibrational frequencies exceed the minimums for compatibility with the antenna servocontrol system; and
- Resist gravitational bending at extreme tilt angles sufficiently to keep the lateral translation of the subreflector within the 9-in. (23-cm) range correctable by the subreflector positioner.

Ignoring diffraction, the blockage calculations were based solely on geometric optics. The quadripod legs were assumed to be opaque. With these assumptions, the blockage includes two components: (1) the shadow cast by the quadripod legs when the antenna is illuminated with a plane wavefront along the axis; and (2) the shadow cast by the legs when the antenna is illuminated by a spherical wavefront emanating from the focus in the subreflector assembly.

One way to reduce blockage is to increase the radius from the antenna axis to the leg-attachment points. Since this option requires excessive fabrication and erection costs, it was rejected. A somewhat more effective way is to make the legs more nearly parallel to the antenna axis. This increases the size of the assembly at the apex, but the assembly has to be enlarged anyway to accommodate the larger subreflector. The most effective way to reduce the blockage is to decrease the widths of the inner and outer faces of the legs, because these widths determine the widths of the shadows.

Various designs incorporating the two surviving changes were analyzed, using a finite-element, pin-jointed-truss mathematical model. The legs were made trapezoidal in cross section; the widths of the inner and outer faces were selected so that the outer faces lay within the spherical-wavefront shadow of the inner faces. Engineering tradeoffs were examined; for example, a reduction in the leg cross section reduces blockage and leg weight, but it also decreases the structural stiffness, as manifested in a decrease in the torsional-vibration frequency and an increase in the gravity displacement of the subreflector.

An optimal design that satisfied all of the competing criteria raised the gain 0.32 dB over that of the existing design. The analysis also lead to the following conclusions:

- Variations in the inner and outer face widths had significant effects on the fundamental torsional frequency as well as on the blockage.
- In all cases, the requirement on the gravity displacement of the subreflector was easily satisfied, and the torsional stiffness controlled the design.
- The pin-jointed mathematical model gives a torsional frequency much lower than that measured on a real structure. A rigid-jointed model, which accounts for the bending and torsional responses of the truss members, gives more realistic results.
- To achieve an adequate fundamental torsional frequency, it is necessary to increase the torsional rigidity of the legs by outrigger braces added at the lower ends.

This work was done by John J. Cucchissi of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "A New Microwave Antenna Quadripod With Reduced Blockage," Circle 75 on the TSP Request Card.*
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Switching System for Redundant Power Supplies

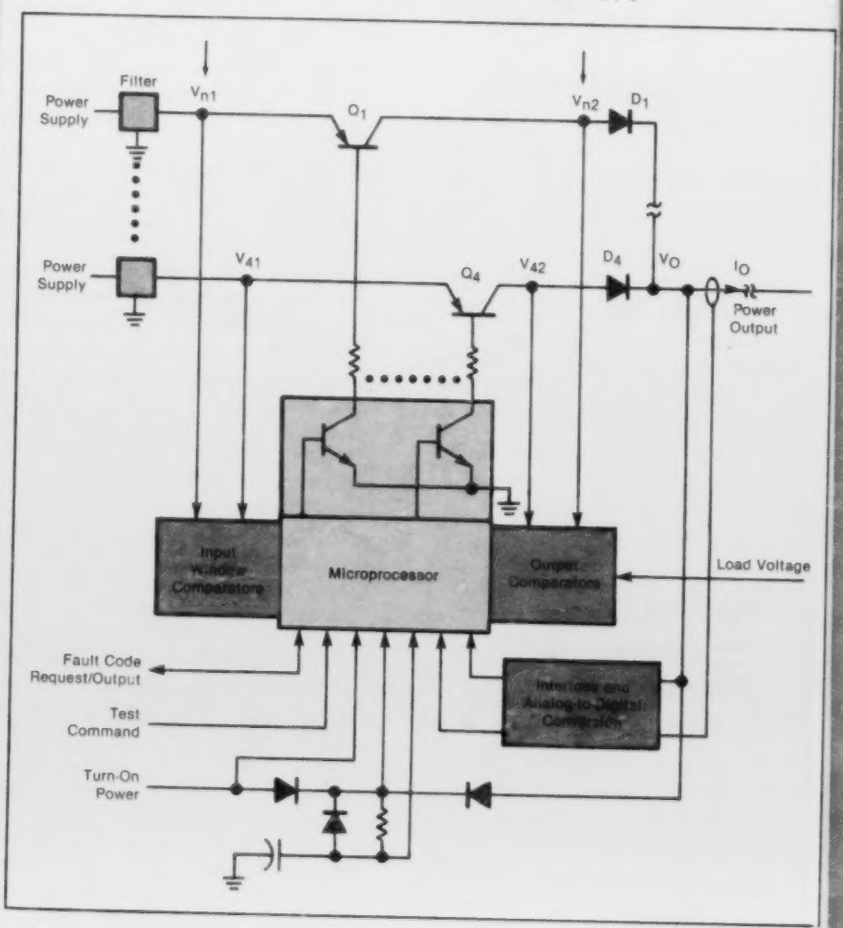
Reliability increases as power is made more nearly uninterruptible.

Ames Research Center, Moffett Field, California

A load-transfer unit connects an airborne computer to a standby power supply in case the primary supply fails. The concept is adaptable to systems in which power interruptions cannot be tolerated; for example, computers with volatile memories, safety equipment, and precise timers.

The load-transfer unit (see figure) operates with four power inputs, any of which can supply all the power required by the load. In the absence of other indications, the unit selects the input to connect to the load according to a priority list that matches the numerical order of the power-supply designations (supply 1 is the first choice, and supply 4 is the last choice). When it is necessary to switch to a different input, the unit does so in half the time it takes for the load functions to begin deteriorating for a lack of power.

Each input source is provided with overvoltage protection in the form of transient-suppressing filters and voltage sensors. When the unit senses an overvoltage on the active input line, it switches the load to the input line of next lower priority that has a voltage within specification. The unit acts similarly when it senses undervoltage at the load. When the power supply in use is not of the highest priority and a higher priority supply returns to the correct voltage, the unit switches the load back to the higher priority supply.



The **Load-Transfer Unit** monitors voltages and load current. The microprocessor controls transistor switches that connect the load to whichever power supply has the highest priority and the correct voltage.

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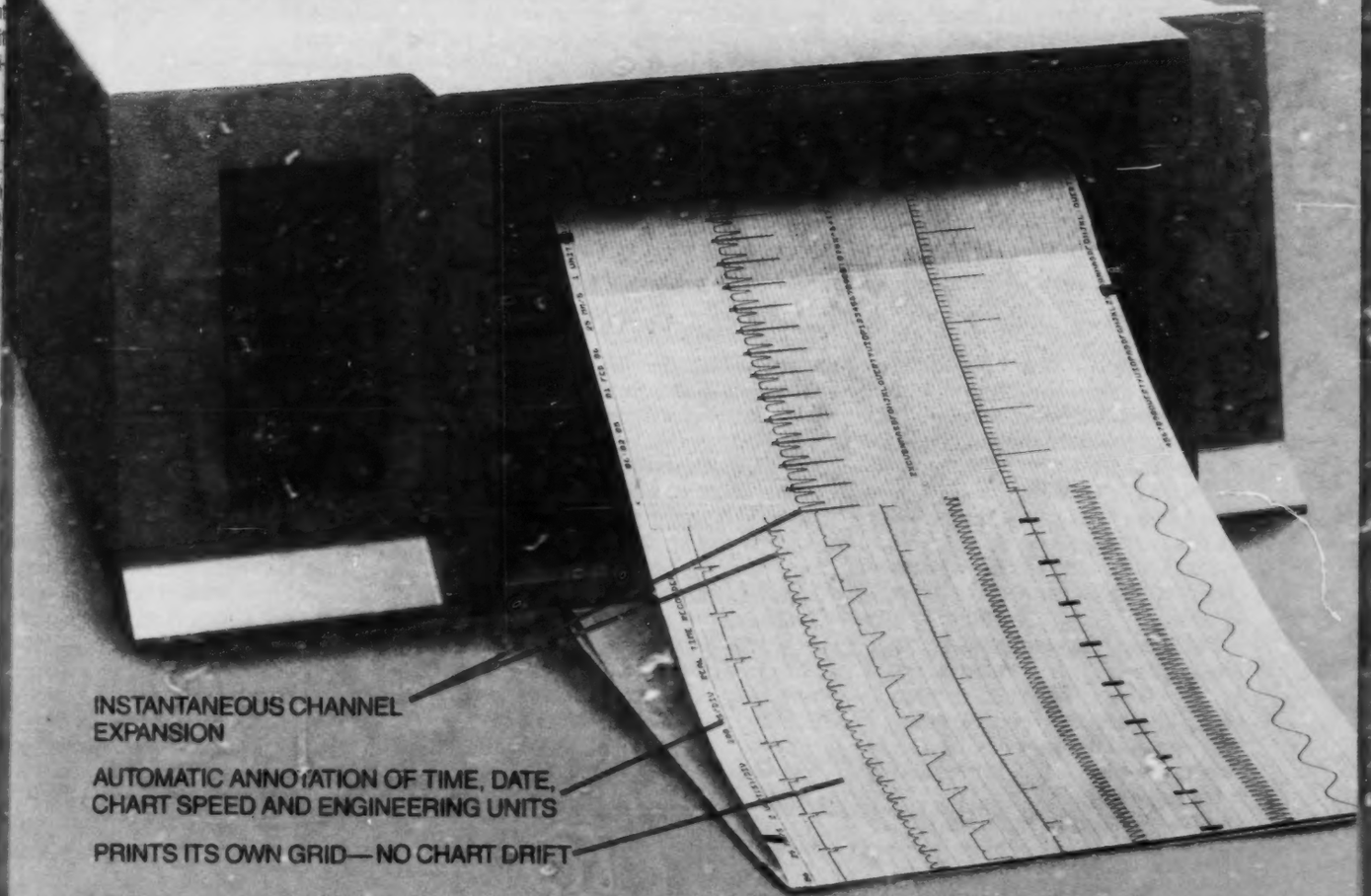
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The unit monitors the output current for overload. If an overload persists for a specified time, the unit latches off until all power is removed, then resets so that it can be energized when power is restored.

The unit is provided with a testing program that exercises each monitoring and switching circuit to verify its proper operation and the isolation of the unit. The test is initiated by a command signal and can be done at any time without degrading the output voltage significantly.

All load-transfer-unit circuits are initially supplied by an internal or external power source that can be turned off subsequently. After the four power supplies are turned on, the turn-on source is disconnected, and the unit is powered by the supply connected to the load. A capacitor stores enough charge to maintain all functions through load-transfer interruptions. If power is lost for enough time to allow the capacitor to discharge, the unit latches off until another turn-on pulse is received.

Upon receipt of a turn-on pulse, the processor checks all sensors for proper status before connecting a power supply to the load. The output and V_{n2} sensors should all give "low" indications, and the V_{n1} sensors should indicate input voltages within specification. If any sensor shows an incorrect condition, the processor removes the affected power supply from the priority list. The remaining operable supplies are then listed in the turn-on priority sequence. The highest priority supply is turned on gradually to prevent excessive inrush currents that would be difficult to distinguish from short-circuit currents. From this point onward, operation proceeds as described above, and the priority list is updated at each pass of the microprocessor program.

This work was done by M. Bradford, R. Grant, and G. Parkinson of United Technologies for **Ames Research Center**. *For further information, Circle 12 on the TSP Request Card.*
ARC-11545

Fade-Free Mobile Communication

A mostly digital system would offer high-quality mobile telephony.

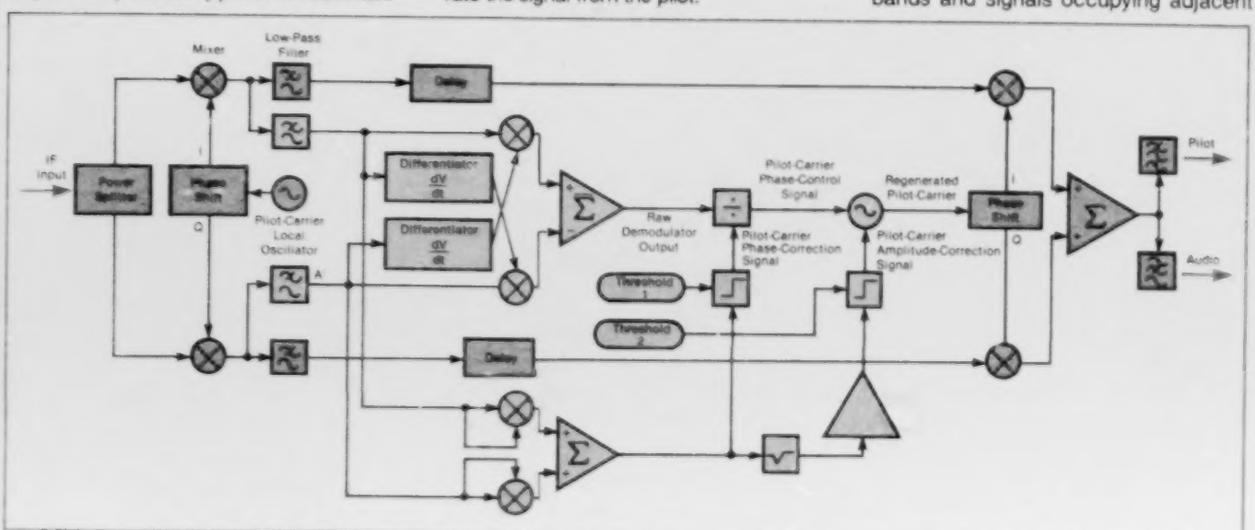
NASA's Jet Propulsion Laboratory, Pasadena, California

A scheme for mobile communication would reduce multipath fading and interference between adjacent channels. The proposed communication system lends itself to an almost completely digital implementation, eliminating costly and bulky crystal filters. The scheme is suitable for satellite-aided or terrestrial mobile communication, including cellular mobile telephony, at frequencies in the 150-to-900-MHz range.

The scheme allows improved modulation, demodulation, and signal processing in an amplitude compandored single-sideband (ACSB) system. In the past, the ACSB technique has been hampered by random amplitude and phase variations caused by the motion of the vehicle through a stationary or nearly stationary pattern of communication signals. The new approach would detect and automatically correct for these unwanted variations and thereby reduce signal fading.

In ACSB, the audio signal is compressed before single-sideband modulation takes place. To provide a reference for the automatic gain control and automatic frequency control at the receiving end, a pilot signal is transmitted with the single-sideband signal. The problem is that, as the channel frequency is increased above about 150 MHz, the pilot tone becomes spread because of the random amplitude- and phase-modulation effects of the propagation medium. The higher the frequency, the greater the spreading, and it therefore becomes increasingly difficult for the receiver to separate the signal from the pilot.

The new system would solve this problem by using a Weaver modulator and demodulator with additional signal processing in the receiver for phase and amplitude correction. The Weaver method for generating and detecting single-sideband signals was first described in 1956 but has found little application until now. Component technology was not up to its requirements for accurate quadrature phase shifts at both radio and audio frequencies and close matching of gain, phase, and delay between its two signal channels. However, recent improvements in components make the Weaver method a practical and economical alternative to the conventional method employing narrow, steep-skirted intermediate-frequency crystal filters for rejecting unwanted sidebands and signals occupying adjacent



The **Receiving Portion** of a modified amplitude-companding single-sideband system compensates for the multipath fading and Doppler shift that hamper mobile communication. Colored blocks in this diagram represent circuitry added to the basic Weaver demodulator for fading correction. The transmitting portion of the system is a basic Weaver modulator.

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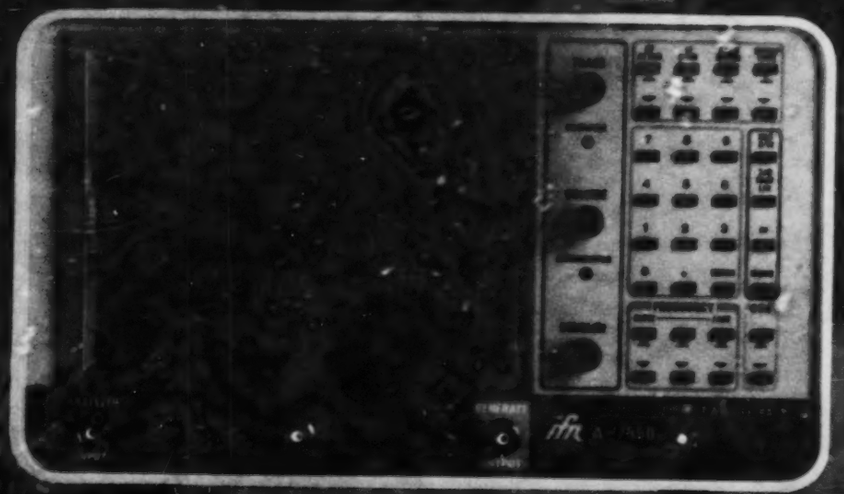

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channels.

The updated ACSB system would be a hybrid pilot-carrier, tone-in-band system in which the pilot tone is actually the radio-frequency carrier. The received signal is amplified and converted to the intermediate frequency (IF) in a conventional way. After mixing identical samples of the faded IF signal with quadrature components of a local-oscillator pilot signal, the receiver produces the pilot and the folded sideband (see figure). This composite signal is band limited and delayed by an amount equal to the delay through the pilot processor before it is applied to a second set of mixers.

The pilot spectrum in the folded baseband at the output of the first set of mixers is contained within a bandwidth equal to the Doppler frequency shift created by the vehicle speed. The pilot spectrum is recovered by low-pass filters with a corner frequency somewhat greater than the maximum expected Doppler frequency. This separates the faded pilot from the sideband information and allows the pilot to be processed by an amplitude-normalized sine/cosine detector so that fading can be detected and corrected.

This work was done by Carl R. Stevenson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 34 on the TSP Request Card.*

This is the invention of a NASA employee, and a patent application has been filed. Inquiries concerning license for its commercial development may be addressed to the inventor, Mr. Carl R. Stevenson, 845 North Woods Avenue, Fullerton, CA 92632. Refer to NPO-16441.

Monolithic 20-GHz Transmitting Module

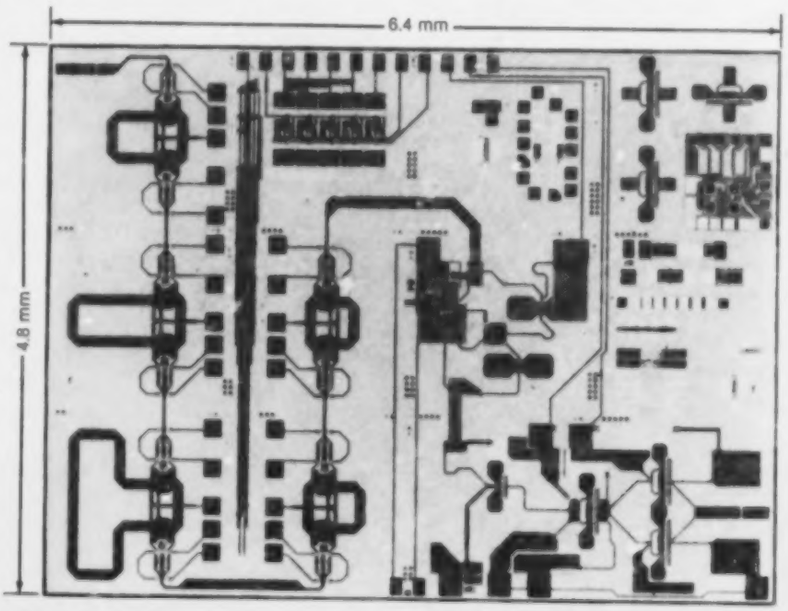
Phase shifts are digitally controlled by a compact and relatively inexpensive unit.

Lewis Research Center, Cleveland, Ohio

A 20-GHz monolithic microwave/millimeter-wave integrated circuit (MMIC) with amplification and phase-shift (time-delay) capabilities has been developed. The use of this MMIC module technology promises to make feasible the development of weight- and cost-effective phased-array antenna systems. Advanced phased-array antenna systems have been identified as a major factor in achieving minimum cost and efficient use of the frequency and orbital resources of future generations of communication satellite systems. The use of MMIC transmitting modules provides for a relatively simple method for phase-shift control of the many separate radio-frequency (RF) signals that are required for phased-array antenna systems. Other methods of providing a large number of controlled RF signals suffer in areas of cost, complexity, weight, and overall system efficiency.

This MMIC module uses microelectronic-fabrication techniques that incorporate a microstrip approach, in which all the active and passive devices required for the various module functions are fabricated on a gallium arsenide semiconductor substrate. The module functions include a phase-shifting circuit with controls that provide a digitally-selectable module phase-shift capability of 0 to 360° in increments of 11.25°. A two-stage buffer amplifier follows the phase shifter to compensate for the phase-shifter losses. Finally, a three-stage power amplifier completes the module.

A photograph of the module is shown in the figure. The module size is 4.8 by 6.4 mm. However, a final version is expected to be smaller. The initial version on the MMIC module has demonstrated all of the desired module functions. The predicted overall module performance specifications are as follows: bandwith 17.7 to 20.2 GHz, gain 16 dB, output power 200 mW, and efficiency 15 percent.



The Monolithic 20-GHz Transmitting Module contains a 5-bit phase shifter, a two-stage buffer amplifier, and a three-stage power amplifier.

An important feature of the MMIC module is its relatively large scale of the integration of many and varied devices. The types of devices include the following: transistors (FET's) used both as switches and in amplifying circuits, capacitors, microstrip transmission lines, resistors and diodes. At the high frequency of 20 GHz, this capability to incorporate monolithically many electronic-circuit functions into a single module provides for the consistency of performance.

The MMIC module does not require external tuning. Such other problems as parasitics and device-value uncertainties, normally associated with non-monolithic techniques are minimized. Also, the use of microelectronic-fabrication methods promises to offer the cost-effective manufacture of the large number of MMIC modules that would be required for an advanced phased-array antenna system.

This work was done by T. J. Kascak of **Lewis Research Center** *and G. R. Kaelin and A. K. Gupta of Rockwell International Corp. Further information may be found in NASA TM-83518 [N84-13399/NSP], "Microwave Monolithic Integrated Circuit Development for Future Spaceborne Phased Array Antennas."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14285

Simulator Tests Controller Performance

A computer model imposes reaction torques on a motor, imitating a dynamically changing real load.

NASA's Jet Propulsion Laboratory, Pasadena, California

A compact servosystem applies simulated dynamic loads, enabling realistic appraisal of a motor and its control system without the inconvenience of attaching a real load. The system can simulate moments of inertia, rotational vibrations, changing load torques, and other characteristics of large or complex loads, without the loads themselves and without the awkwardness (and inaccuracy) of gravity-compensating devices that may have to be used with such loads.

The system compares the actual shaft rate and shaft position of the motor under test with the corresponding data from a complete nonlinear real-time computer model of the dynamic performance of the load to be simulated. The system controls a load-simulating motor, which is mounted concentrically on the shaft of the motor under test.

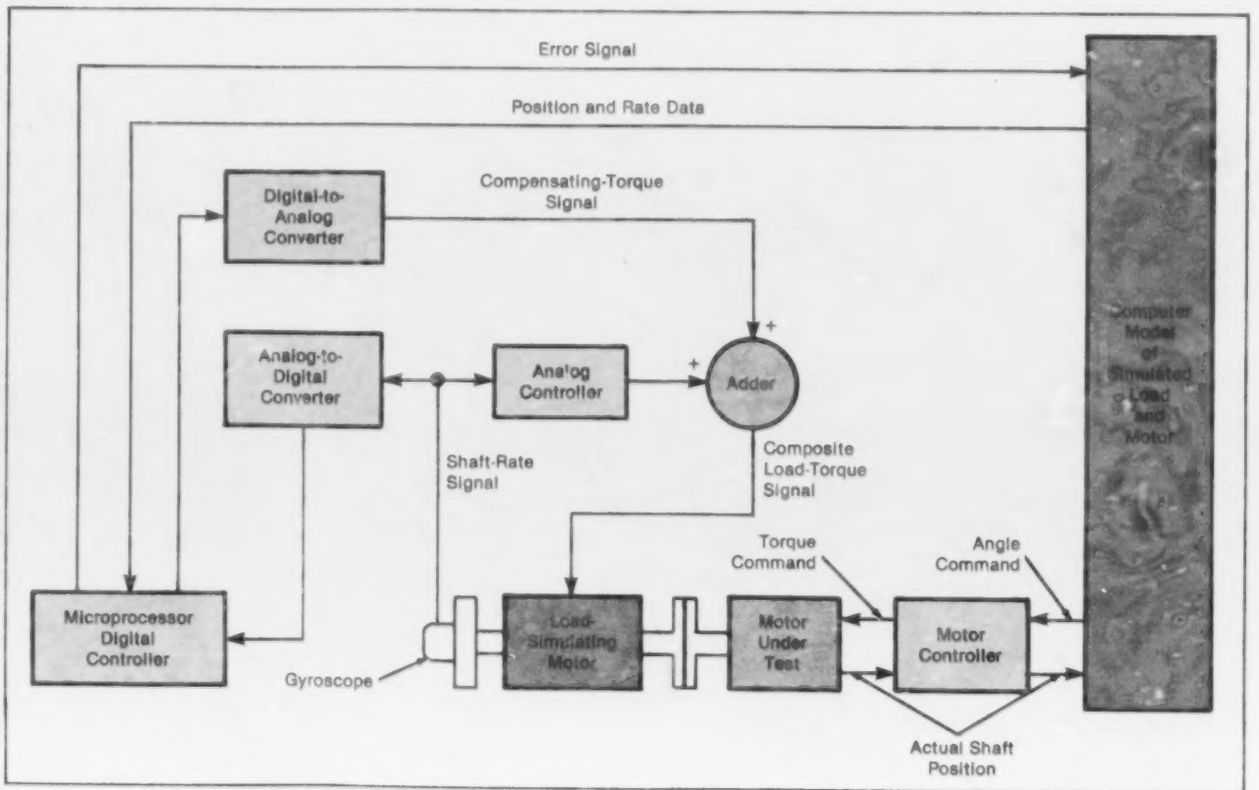
The system includes hybrid analog and digital control (see figure). An analog circuit differentiates the rate signal from a gyroscope on the shaft to determine the actual acceleration, from which it develops a primary torque signal that closely approximates the load-inertia reaction torque. Meanwhile, a digital controller develops a small secondary torque that adds noninertial torques and compensates for most of the error in the primary torque. This brings the total torque close to the value needed to simulate the load dynamics.

The simulator includes stability and drift compensation of the analog loop. It also includes automatic safety devices.

The actual shaft inertia can be kept much smaller than the inertia being simulated: a ratio of more than 10 to 1 has been achieved. Changing inertia loads can be simulated without interruptions to rearrange the apparatus: the system simply follows changes in the driving dynamic model.

Torque transducers are not required. There is implicit verification of the accuracy of the conversion from the command signal to the torque exerted by the motor under test because conversion errors show up in the angular tracking error and are automatically taken into account. The test-control computer monitors the angular tracking error to determine whether the motor under test is converting properly.

This work was done by Michael F. Lembeck and Robert D. Rasmussen of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 76 on the TSP Request Card.*
NPO-15744



Hybrid Analog and Digital Control of the load-simulating motor enables accurate, fast responses to the performance of the motor under test and allows the simulation of changing load characteristics.

The Inland Motor Team Philosophy: Our PWM Servo Amps Deliver Linear Amp Performance—at Twice the Efficiency.

Until recently, precision DC servo systems have relied upon linear amplifiers. These "linears" have served well, but their inherent low efficiencies (typically less than 50%) and large size make them inappropriate for many high power applications. Efficient Pulse-Width-Modulated "switching" amplifiers, or PWMs, are often used as an alternative. Unfortunately, PWMs generally fall short of the performance demands required in high precision applications.

Now, Inland Motor is eliminating system compromise through PWMs suitable for brush-type and brushless DC motors. These PWMs deliver greater than 90% efficiency, so that thermal concerns are virtually nonexistent. Inland's compact, modular PWMs are self-enclosed to shield RFI and include internal filters which attenuate EMI. Inland PWMs use power FET technology that allows switching frequencies above the audible region (20 kHz).

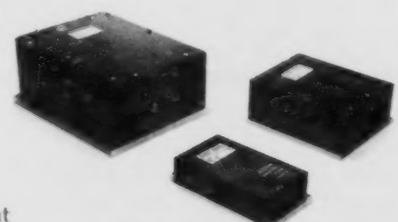
The heart of our PWMs is an integral high performance current-loop. Inland PWMs feature internal current feedback which senses and controls output current, thereby minimizing the effects of motor inductance, load disturbances and changes in ambient conditions on system performance. The internal current-loop provides a 6 kHz current-loop bandwidth with phase shift less than 10 degrees up to 1 kHz. Overall current-loop linearity, measured as a ratio of output current to command signal, is +/– 2% over the entire modulation range. The internal current-loop also provides current limiting and short circuit protection.

Current-Loop Amps

In the current-loop configuration, the amplifier accepts an analog +/– 10 volt command input signal, corresponding to positive through negative full-scale current to the motor. The command input is summed with the negative current feedback signal, thus closing the current-loop internally. The error signal from this summing junction is processed by a gain and compensation stage and fed into a modulator.

The modulator produces a 20 kHz pulse width modulated squarewave which is fed into the power stage (H-bridge). The H-bridge controls the flow of current from the power bus into the load through discrete switching action of the power FETs. The load inductance smooths the "chopped" 20 kHz PWM output of the amplifier to produce low-ripple output current. The high switching frequency produces near unity form factors even with relatively low inductance loads.

The current-loop configuration provides accurate control of motor torque, which is proportional to motor current. Velocity and position control require closing external loops around the current-loop.

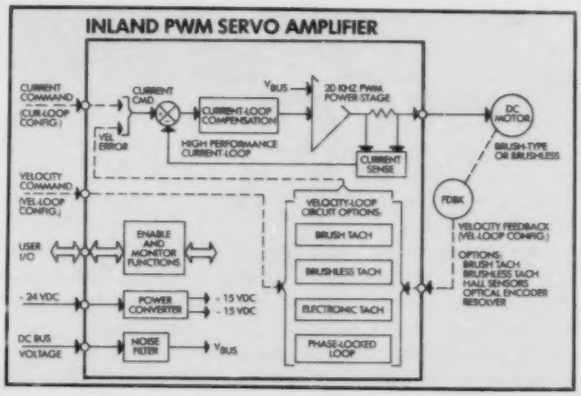


Circle Reader Action No. 423

Velocity-Loop Amps

In this configuration, the amplifier accepts an analog +/– 10 volt command input signal, corresponding to positive through negative full-scale motor velocity. The command is summed with a negative velocity feedback signal which comes from an external velocity transducer. The summing is handled internally, thus closing the velocity-loop. For most applications, utilization of a DC tachometer yields the best results, though a brushless tach, pulse tach or some other digital technique may be used to obtain velocity information instead. The error signal from the velocity-loop summing junction is processed by a gain and compensation stage and fed to the inner current-loop. The result is accurate, responsive velocity control.

Phase-Locked-Loop Amps



Our phase-locked-loop option is ideal for applications requiring precise, steady state velocity regulation. Motor speeds can be regulated to 0.01% and can operate down to 50 RPM. This velocity-loop is closed around the high performance current-loop built into every Inland amplifier.

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Transponder System for High-Frequency Ranging

Distances are measured by phase differences at convenient frequencies.

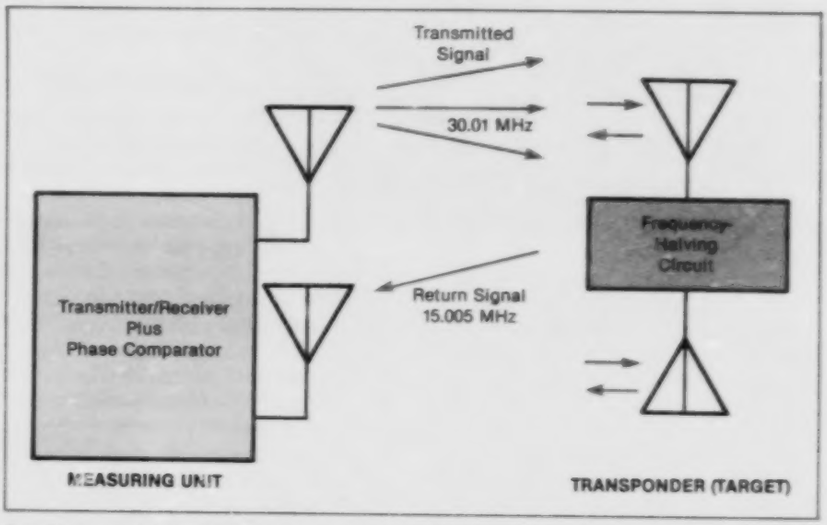
Lyndon B. Johnson Space Center, Houston, Texas

A transponder system (see figure) uses the phase difference between transmitted and reflected high-frequency radio waves to measure the distance to a target. To suppress spurious measurements of reflections from objects near the target at the transmitted frequency and its harmonics, the transponder at the target generates a return signal at half the transmitted frequency. The system should be useful in such applications as surveying, the docking of ships, and short-range navigation.

The outgoing signal could be sent at any convenient frequency. In the experiments 30.01 MHz was the chosen value because it is well suited for the generation and processing of reference, offset, and intermediate-frequency signals.

The transponder target includes a short dipole antenna with a frequency-halving circuit at its middle. This circuit consists of a varactor and two inductor/capacitor circuits, one resonant below 15 MHz and one resonant above 30 MHz.

The 15.005-MHz return signal generated by the transponder is locked in phase to the 30.01-MHz transmitted signal that impinges on the antenna. As measured at 15.005 MHz, the total phase shift sustained by the signal as it travels from the transmitter to the transponder, then back to the receiver is $2\pi d/\lambda \pm \pi$, where d = the distance to the target and λ = the wavelength at 15.005 MHz. The $\pm\pi$ ambiguity arises from an inevitable uncertainty in the initial phase state of the frequency-halving circuit. The ambiguity can be resolved by an initial calibration at turn-on or by the introduction of suitable amplitude, frequency, or phase modulation.



The **Transponder Ranging System** measures distances in terms of the phase difference between the return signal and a phase-locked reference signal. The return signal generated by the transponder is phase-locked but at half the transmitted frequency.

In the receiver the 15.005-MHz return signal is mixed with a 15.000-MHz signal derived from the master oscillator. After low-pass filtering, the mixer output is proportional to

$$\cos\left(\frac{\omega t}{2} - \frac{2\pi d}{\lambda} \pm \pi\right)$$

where $\omega = 2\pi \times 5$ kHz. The receiver also generates a 5-kHz reference signal locked to the master oscillator, proportional to cos ($\omega t/2$).

The two 5-kHz signals are separately filtered, amplified, and limited, using standard FM limiters. The limiting process conditions the signals for use in a start/stop counter that counts the delay (typically a few nanoseconds) between the zero crossings of the two signals. When corrected for the phase ambiguity, this delay gives the distance to the target.

An experimental version of the system has been tested with some success. Range measurements were made out to about 350 ft (107 m).

This work was done by Christopher L. Lichtenberg, Paul W. Shores, and Herbert S. Kobayashi of **Johnson Space Center**. *For further information, Circle 69 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20912.

A Priority Protocol for Token-Ring Networks

Key messages are guaranteed access to a local-area network during peak loads.

NASA's Jet Propulsion Laboratory, Pasadena, California

A new priority protocol controls access to a token-ring local-area network (LAN) of digital-communication stations over a widely ranging mix of low- and high-priority traffic. The protocol, called a round-robin priority scheme (RRPS), introduces only a small overhead and therefore degrades system performance only minimally.

The RRPS accommodates the different response requirements of a variety of users and applications (see figure). In an

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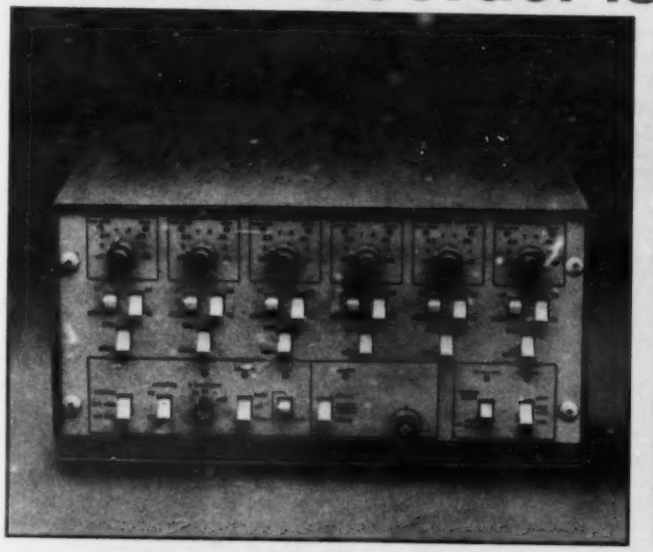

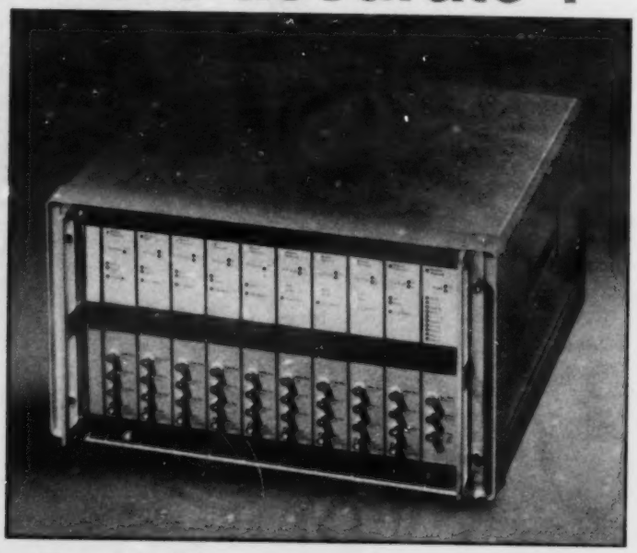

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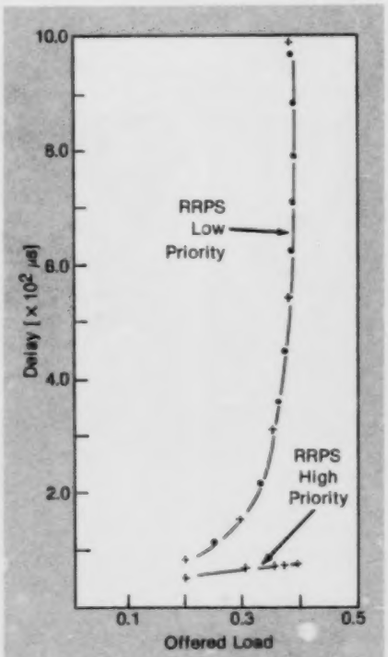
academic environment, for example, it will ensure that the network responds more rapidly to a service request from a network manager than to a request from a user and that faculty users get faster responses than student users during periods of heavy message traffic. In real-time service, RRPS will provide a constant response delay for voice channels so that intelligibility of conversations is guaranteed. In production applications, it will make sure that control signals from a central computer have preference over routine bulk traffic, such as transfers of file or image data.

Ordinarily, a token-ring network is vulnerable to overloading and unreliable because each station is an active element in network operation; the failure of any station halts the entire network. The RRPS, however, employs distributed priority control so that operation does not depend on any single station. Any station can be assigned dynamically to be the monitor station to poll the status of all the other stations. A high-priority data packet can be sent out by any station.

Any station can send packets of a single priority level or of mixed priorities. The potential for sending a packet of any given priority is equally distributed among all stations regardless of their positions in the ring.

The access algorithm of the RRPS operates in the following way:

- Every message packet has a priority level for gaining access to the ring.
- The priority level of a station is the same as the highest priority of the packets in that station.



Delay-Throughput Characteristics in RRPS Scheme

- A station can capture a free token having the same or lower priority level.
- If the priority level of a requesting station is higher than the level of a free token, the requesting station marks its level on the token. A free token of the same priority will then be issued after the current transmission is completed. The free token will bypass low-priority stations and be seized by the requesting station; however, an intermediate requesting station with equal or higher priority may capture the token before it reaches the original requesting station.
- If the priority level of the requesting station is equal to the level of a busy token, the station will mark the round-robin bit in the token.
- A destination station sends an acknowlegment back to the source station after receiving a packet. A new free token with the new priority-requesting

The Round-Robin Priority Scheme ensures that high-priority stations gain access to the local-area network, regardless of the load imposed on the network. These curves result from the mathematical model of a typical LAN. As the load increases, high-priority requests are delayed hardly at all beyond the normal delay. The prompt service is at the expense of low-priority requests, which can be delayed substantially at high loads.

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level is put back into the ring.

- The token returned by a requesting station is checked to see whether it has the same requesting priority as that of the source station and whether the round-robin bit is set. If both conditions are met, a new free token with the requesting-priority level is put on the ring, and the round-robin bit is reset. If the round-robin bit of the old token was not set, then the same station continues to be served.
- If no more packets need to be served, a new free token with zero priority and round-robin bits is put on the ring.

This work was done by Howard T. Liu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 97 on the TSP Request Card.*
NPO-16683

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Global Timing With Low- and High-Orbiting Satellites

Clocks would be synchronized within nanoseconds.

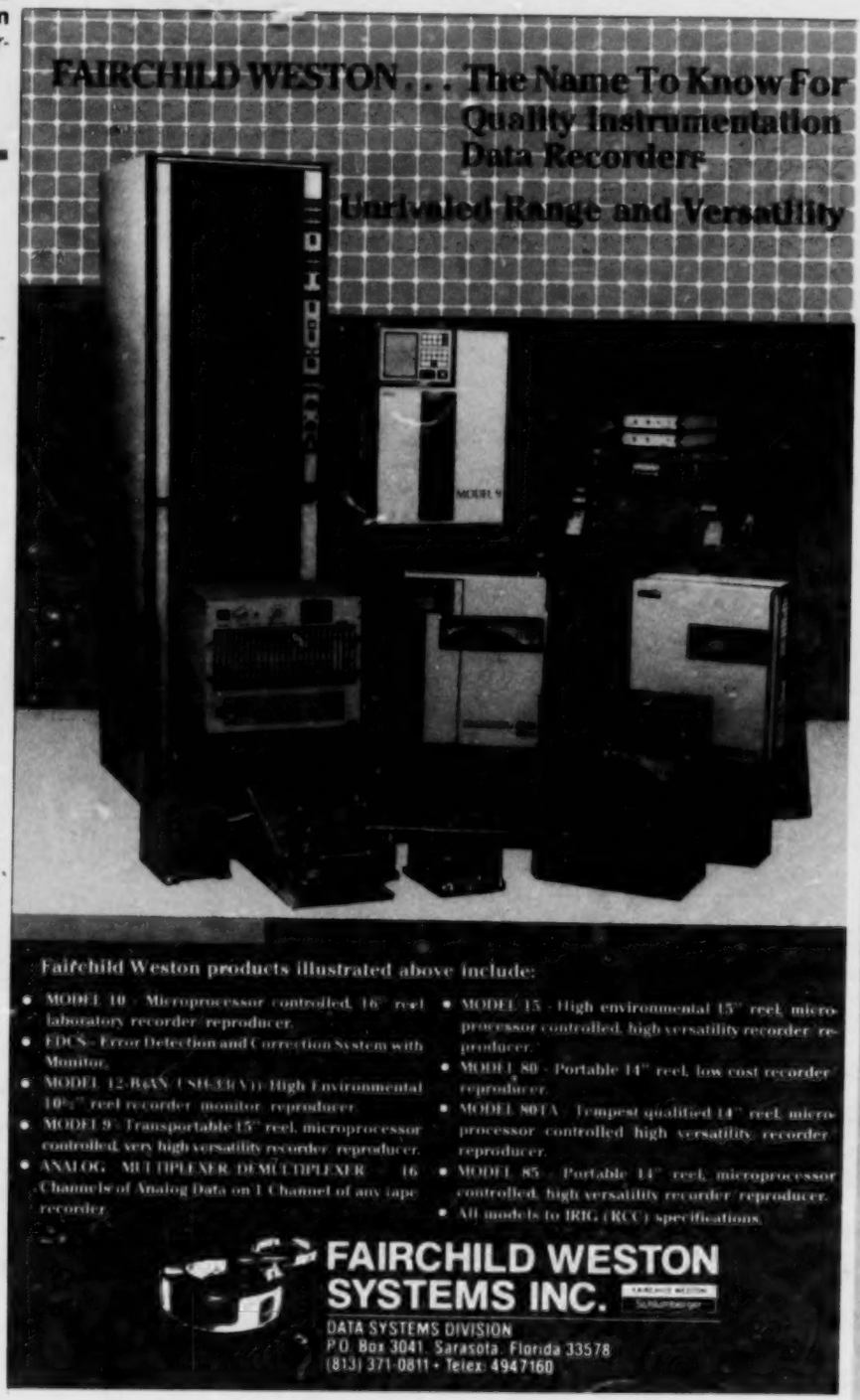
A report summarizes a method for synchronizing clocks at intercontinental distances employing satellites of the Global Positioning System (GPS) in high Earth orbit and a transit satellite in orbit at the relatively low altitude of about 1,300 km. When fully implemented, the method is expected to supply precise time measurements for worldwide communication and navigation.

The comparison of distant clocks is based on differences in the arrival times of signals from the GPS satellites. These differences contain information about the offset between the clocks and the propagation and instrument delays suffered by the signals. Synchronization can be performed if the positions of the two Earth stations and the satellite orbits are known and if the delays are properly calibrated.

When two sites are widely separated, the intervals during which both have a view of the same GPS satellite are often too short for accurate synchronization. Furthermore, the satellite must often be observed near the horizon, so the signals acquire additional delay errors from long paths through the troposphere.

In the proposed system, each ground station looks at a different GPS satellite, which is chosen to be far enough above the horizon so that the tropospheric delay error is minimal. The GPS includes 18 satellites, several of which are usually accessible to the ground stations and simultaneously in view from the transit satellite. Thus, the intervals available for intercontinental time comparison are longer than with a single GPS satellite.

A differential GPS pseudorange measurement is made between the transit satellite and each of the ground sites. A second difference is then taken between the GPS measurements. A precise clock is not needed on the transit satellite because the second difference cancels the transit-clock error.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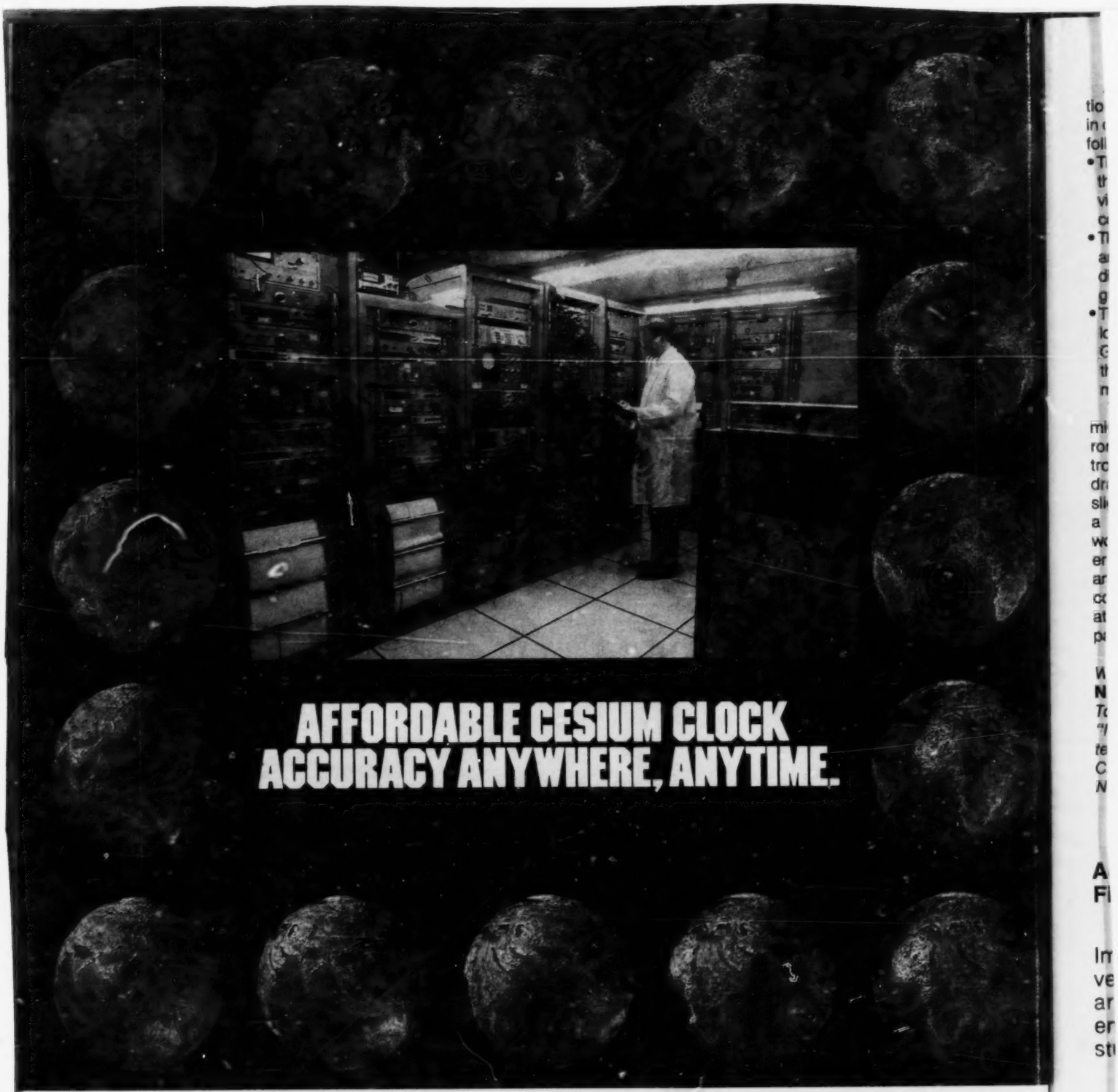

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Circle Reader Action No. 354

Although in principle the transit station could be on the ground, placing it in orbit is advantageous because of the following:

- The ground track covers a large part of the Earth in a short time, thereby providing transit service for a worldwide community.
- The station is above the troposphere and therefore does not introduce the additional tropospheric delay error of a ground station.
- The rapidly changing geometry of the low orbit improves the precision of the GPS orbital-position measurements, thereby improving the accuracy of time measurements.

The 1,300-km altitude was chosen to minimize the combined effect of two error sources: A lower orbit would introduce uncertainty due to atmospheric drag and imprecise knowledge of the slightly aspherical geopotential field. In a higher orbit, time measurements would be more sensitive to GPS position errors. Considering all error sources and using conservative assumptions, a computer simulation showed that times at distant points on Earth can be compared within 1 to 2 ns.

This work was done by Sien-Chong Wu and V. John Ondrasik of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Method and Means for Low-Cost Intercontinental Time Synchronization," Circle 39 on the TSP Request Card.*
NPO-16407

Advanced Transceivers for Firefighters

Improvements in convenience and dependability are based on user preferences and propagation studies.

A report presents the concept of an improved portable radio transceiver for firefighters. The concept was based in part on a study of the propagation of radio waves in such environments as high-rise buildings, ships, and tunnels. Communications devices currently in use and the regulations affecting them were considered. The study also took into account the possible health hazard posed by personal transceivers and the needs and wishes expressed by firefighters in interviews.

The interviews were held with fire-service officials in 10 diverse cities in the United States. The officials were asked about fire-ground communications problems and were encouraged to offer suggestions for improvements.

In the propagation study, extensive measurements were made in various structures at frequencies of 46, 154, 458, and 809 MHz. The sites were the Conrad Hilton Hotel, Chicago; the MGIC Plaza East office building, Milwaukee; the Washington (D.C.) Metro tunnel near the L'Enfant Plaza station; and the U.S. Navy heavy cruiser *Des Moines* at the Philadelphia Naval Base.

Additional design guidance came from a study of the possible health hazard of personal radio transceivers. The study found that the energy-absorption rates of the body for a representative radio were well within standards. Caution is needed, however: the highest internal fields (measured in simulated human tissue in a dummy) were found in the area of the central nervous system. This means that further experimentation is needed before health implications can be fully assessed.

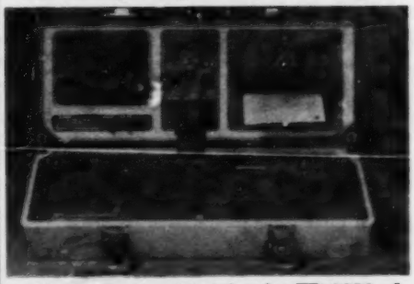
The conceptual radio would be attached to clothing to allow hands-free use; it would be voice-actuated with the microphone worn at the throat. The speaker would be placed near the wearer's shoulder. The flexible antenna would be placed either horizontally across the shoulders, vertically at one shoulder, or on the transceiver itself.

The 450-MHz uhf band was selected for transmission on the basis of the propagation experiments. Although a radio with this frequency band would be more expensive and less energy efficient than others, its performance would be superior. Each radio would be able to operate at six frequencies in the band. The user would be assigned one of these frequencies, which would be selected by locking it in with a key or by some other simple adjustment. The range would be 600 meters under relatively unimpeded conditions — enough for fire-ground communication in all but the most exceptional situations. The range would be less when buildings or other obstacles interfere.

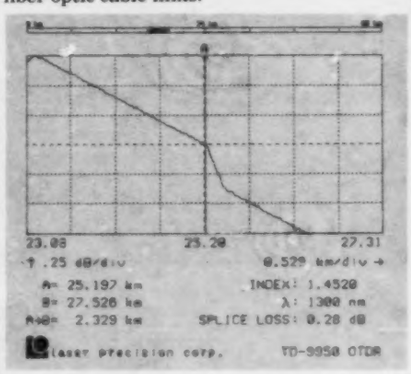
This work was done by Benjamin D. Blood, Om P. Gandhi, and Robert E. Radke of REMIC Corp. for **Marshall Space Flight Center**. *To obtain a copy of the report, "Firefighters Communication System — Final Report," Circle 35 on the TSP Request Card.*
MFS-27040

The ultimate OTDR for fiber optics

Laser Precision, who developed the world's first totally integrated Optical Time Domain Reflectometer, has now introduced the ultimate OTDR for optical cable testing and fault locating. Designed for all wavelengths,



singlemode or multimode, the TD-9950 offers plug-in 850, 1300, 1550, and dual wavelength 1300/1550nM modules. The TD-9950 combines high performance with user-friendly software and built-in digital X-Y plotter for easier, faster characterization of fiber optic cable links.



In the automatic splice loss mode, the amount of loss at the splice point is accurately measured to within 0.01dB and is instantly displayed on the CRT. Only a single marker is required to establish the splicing location on the CRT. This location is maintained going from fiber to fiber. No reprogramming required. The real-time display acts as a "live monitor" so that fiber core alignment can be optimized for minimum loss.

For fault locating, the dual cursors can be used to accurately measure the distance of a fault from any point along the cable, such as a documented splice, to help pinpoint its exact location. All of the data—dB loss, absolute distance, and relative distance measurements—are clearly spelled out on the CRT and hardcopy printout, so that cable problems can quickly be corrected.

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Specifications include: ±0.01% base-accuracy, 0.01dB resolution, 20dB min. one-way backscatter range, 131 km distance range, one meter resolution, dual cursors, and real-time display.

For more information, contact: LASER PRECISION CORPORATION, 1231 Hart St., Utica, NY 13502, or call (315) 797-4449

Circle Reader Action No. 427

Digital Control of Durability-Testing Burner Rigs

Surface temperatures are controlled more precisely than before.

A report describes hardware and software that implement the hybrid digital control of two Jet A-1-fueled, mach-0.3 burners from startup to completion of a preset number of hot-corrosion/flame-durability cycle tests of materials at 1,652 °F (900 °C). Material-durability testing in dynamic flame combustion products is in common use in the gas-turbine and high-temperature-alloys industries. Heretofore, the determination and control of the true surface temperature has been a continuing problem and a source of uncertainty in the results obtained from such tests.

In the reported system, the determination and control of the surface temperature were accomplished by the use of a microcomputer programmable in the BASIC language and of a data-acquisition and -control unit; the two components were connected together by an IEEE-488 bus. The absolute specimen temperature was controlled to ±3 °F (±1.7 °C) by digital adjustment of the fuel flow using a proportional-integral-derivative control algorithm. The specimen temperature was within ±2 °F (±1.1 °C) of the set point more than 90 percent of the time. Pressure control was achieved by digital adjustment of the combustion airflow using a proportional control algorithm. The burner pressure was controlled at 1.0 ±0.02 psig (6.9 ±0.14 kPa gauge).

Logic schemes were incorporated into the system to protect the test specimen from abnormal test conditions in the event of a hardware or software malfunction. Also, the special and difficult problem of the transitions from heating to cooling and back to heating, presented by cyclic testing, can be easily handled in a positive way through software by using a hardware-generated burner-position signal.

The digital control avoids some of the problems associated with the analog control systems commonly used in such tests. The fuel and air valves are adjusted by small incremental steps, as opposed to the large, rapid variations possible with analog control. The result is a more accurate control of the test conditions, especially during long-term tests, which are unattended much of the time. The interpretation of test results for specimens tested under varying and sometimes questionable conditions is greatly suspect. The more accurate control of parameters possible with a digital control greatly reduces the uncertainty of the results.

This work was done by Daniel L. Deadmore of **Lewis Research Center**. *Further information may be found in NASA TM-86959 [N85-21321/NSP], "Digital Temperature and Velocity Control of Mach 0.3."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

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Low-Concentration-Ratio Solar-Cell Arrays

Many compact, lightweight concentrators would be combined to produce about 100 kW.

A paper presents a design concept for mass-producible arrays of solar electric batteries and concentrators that can be tailored to individual requirements. The arrays are intended primarily for space stations needing about 100 kW of power. However, the modular, lightweight, compact, and relatively low-cost design may also fulfill the requirements of some terrestrial applications.

An array would consist of sunlight-concentrator modules with a geometric concentration ratio of about 6. Either silicon or gallium arsenide solar cells could be used with the concentrators.

The idea behind the concentrator array concept is to substitute cheaper reflecting surfaces for a large portion of the more-expensive solar-cell material. The low concentration ratio makes accurate Sun pointing unnecessary; a deviation of $\pm 8°$ to $\pm 10°$ off axis produces only a modest drop in power, but as little as $1°$ of error in a high-ratio concentrator causes a drastic drop. For the low-concentration-ratio approach to be successful, however, the concentrator must be lightweight and be fairly efficient.

Each concentrator in an array would be an inverted truncated pyramid formed by four reflector panels with a top opening of about 0.5 m square to collect sunlight and a 20-cm-square bottom lined with solar cells. The panels would be made of aluminized plastic film.

Two arrays would extend like paddles on opposite sides of the space station. Each array would be 34 m long and 648 m wide. Articulated rotary booms, each having two degrees of freedom would point the arrays to the Sun. A system of hinges, pulleys, cables, springs, slides, and latches folds the arrays into compact rectangular solid blocks for storage and transportation, then unfolds them for service.

The arrays can be built with currently available materials. Pultrusions, injection-molded parts, and composite materials can be used extensively to keep weight low. For added flexibility in design and construction, the silicon and gallium arsenide solar-cell panels are interchangeable.

This work was done by Michael S. Biss and David A. Reed, Jr., of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 139 on the TSP Request Card.*
MFS-28022

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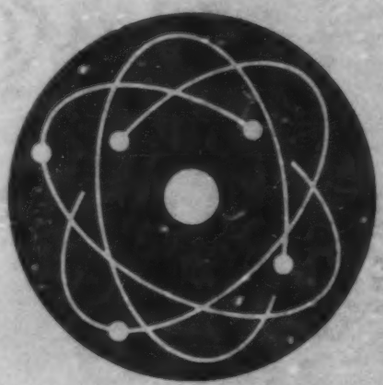

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Increasing the Deposition Rate of Silicon

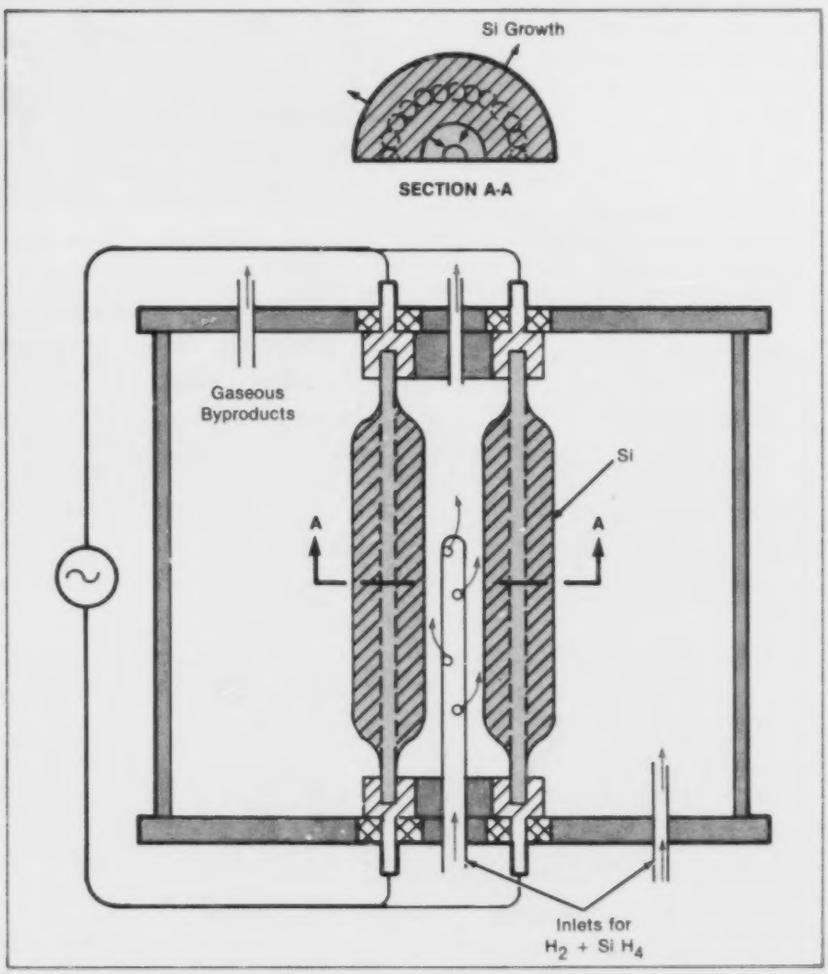
A hollow cylinder is the key to a fourfold increase in the deposition rate.

NASA's Jet Propulsion Laboratory, Pasadena, California

A modified Siemens reactor enables chemical vapor deposition (CVD) of silicon to occur simultaneously on the inner and outer surfaces of a hollow cylinder, resulting in an increase in the mass of silicon deposited per unit time. The conventional Siemens process uses a single solid cylindrical rod, initially of a small radius, with silicon deposition occuring on the outer surface only.

The new outer reactor for silicon deposition shown in the figure would be made from quartz or stainless steel. The hollow cylinder could be either a single resistance-heated hollow cylinder about 5 to 10 cm or greater in diameter or 1-cm-diameter rods aligned in circular channels at the top and bottom, the initial circles being 5 to 10 cm in diameter or greater. The cylinder is resistance-heated throughout the deposition period to about 1,000 to 1,200 °C. A reactor may contain one or more of the hollow cylinders. The reactant gases are introduced through gas ports or jets into the interior and exterior spaces of the hollow cylinders. Any one of the chlorosilanes, with hydrogen or without hydrogen, or silane itself can be used as the feedstock.

The mixture of unreacted gases is allowed to escape from the outer reactor through exit ports. One or more components of this mixture can be sepa-



The **New Siemens Chemical-Vapor-Deposition Reactor** uses a 5- to 10-cm-diameter hollow cylinder made of 1-cm-diameter solid silicon rods. The tightly-packed resistance-heated rods are aligned in circular channels at the top and bottom. Silicon deposition occurs simultaneously on the inner and outer surfaces of the hollow cylinder.

rated and recycled in the process.

At the end of the growth, the hollow cylinder has been filled to a cylinder of radius R/2 inward and outward to form a solid rod of radius R. As a result, during this time period, the production rate with the hollow tube is four times that obtained with the conventional rod.

This work was done by Ralph Lutwack and K. Allan Yamakawa of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 22 on the TSP Request Card.* *NPO-15911*

Tandem-Mirror Ion Source

Ions are produced in a broad range of energies.

Marshall Space Flight Center, Alabama

An improved ion source produces a beam of ions at any kinetic energy from 1 to 1,000 eV, with little spread in energy or angle. Such ion beams are useful in studies of the surface properties of materials, surface etching, deposition, and the development of plasma-diagnostic instrumentation.

In the source (see figure), a heated, negatively biased filament supplies electrons that produce ions by collisions with atoms of a working gas. The electrons spiral about the lines of a magnetic field generated by five segmented solenoidal field coils. The spiral motion lengthens the path that the electrons must travel before leaving the ionization chamber; this increases the probability of collisions with the gas atoms, thereby increasing the ionization efficiency.

The currents in the coil segments are adjusted so that the field at the extraction end is about 5 times that at the ionization end and about twice that of the adjacent segment. The exact taper of the magnetic field depends sensitively on the desired ion energy and current. The field taper effectively spreads the electrons over the ionization chamber (for beam uniformity). The field-line constriction at the high-field (extraction) end constitutes a magnetic mirror that has little effect on the ions but reflects many electrons back into the chamber, where they undergo additional ionizing collisions.

In prior ion sources, the variation of potential along the filament caused excessive beam-energy spread. In this source, the filament is placed outside the ionization chamber. The chamber thus becomes an equipotential region; consequently, all ions are created at the same potential and emerge with little energy spread.

The other of the two tandem mirrors is an electrostatic grid placed behind the filament. The grid is biased at the same potential as (or at a slightly more negative potential than) that of the filament so that electrons launched back from the filament are repelled forward into the ionization chamber instead of being lost to the walls. This makes more electrons available for ionizing collisions; with a planar grid, the output is increased by about 50 percent. (The additional output gained by the negative bias of this grid is only a few percent so that the expense of this bias power supply may not be justified.)

Previously, a grid was seldom placed beyond the extraction grid. Without the grid, a series of concave equipotentials that formed spontaneously in the output beam caused the beam to diverge. Some prior source designs included a shielding

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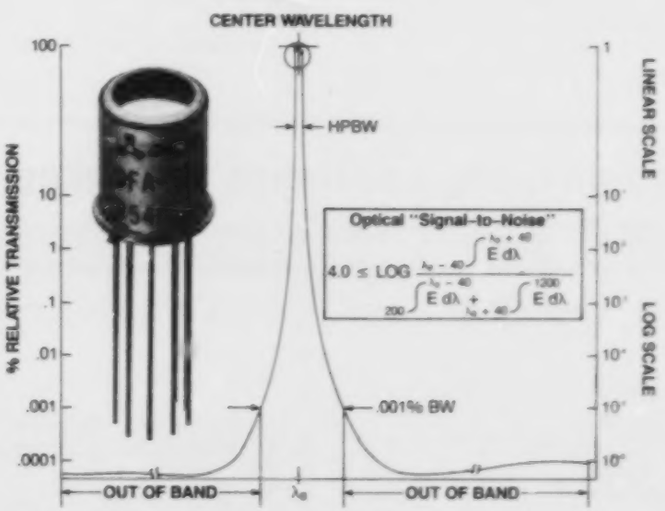

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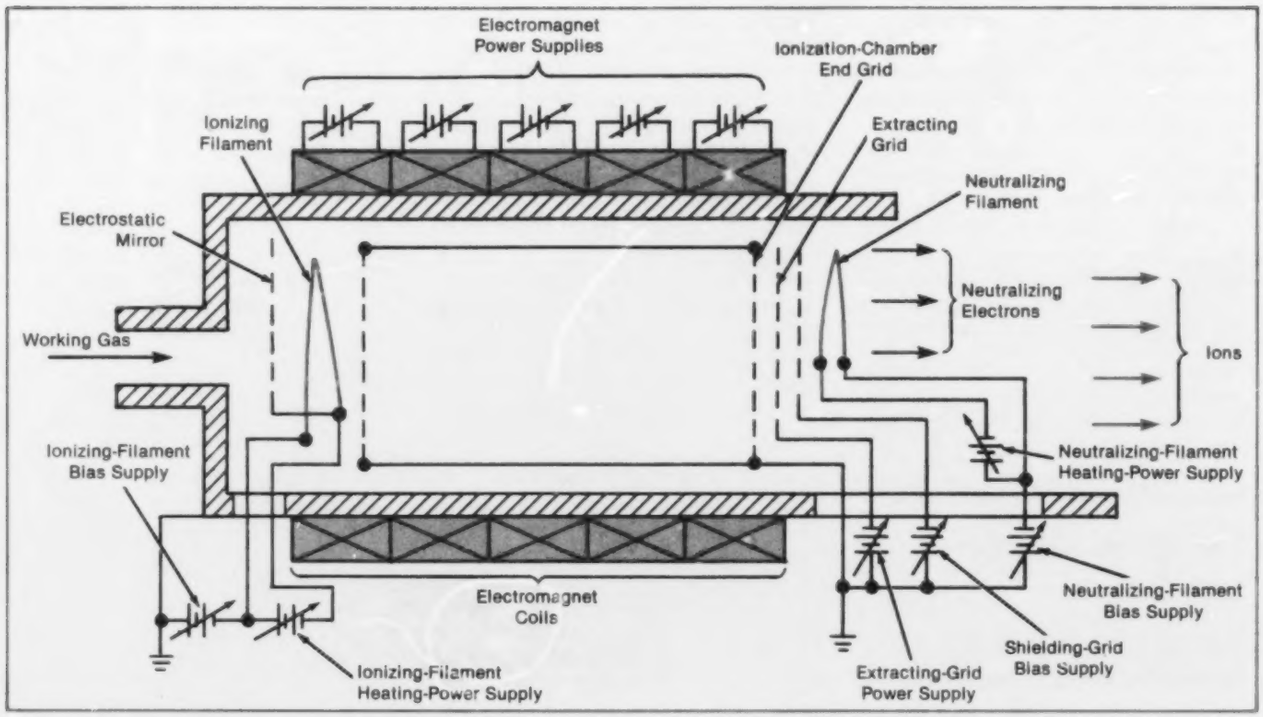

The **Tandem-Mirror Ion Source** uses electrostatic and magnetic fields to keep electrons in the ionization chamber and to assure a uniform output ion beam having low divergence in energy and angle.

grid at ground potential to establish a planar reference-potential surface, thereby reducing the beam divergence. In this source, additional flexibility is obtained by operation of the shielding grid at a slight bias. A small bias does not distort the reference surface greatly but does enable the output to be maximized by matching electrically the grid-hole sizes to the intergrid spacing. The effect of this bias is especially pronounced at energies below 10 eV, where the output is critical.

This work was done by A. P. Biddle, N. H. Stone, D. L. Reasoner, W. Chisholm, and J. Reynolds of **Marshall Space Flight Center.** *No further documentation is available.*

Inquires concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28122.

Field Funneling and Range Straggling in Silicon Detectors

Conditions for operation as charged-particle detectors are tentatively established.

NASA's Jet Propulsion Laboratory, Pasadena, California

The magnitudes of field funneling and range straggling have been determined in silicon-surface-barrier (Schottky-barrier) charged-particle detectors (SSBD's) through the measurement of charges collected from alpha-particle tracks. The method used may be extended to the straightforward measurement of charge collection from heavy-ion tracks in these and other semiconductor devices. Such measurements can be used to assess single-event upsets in integrated-circuit chips, with a view toward making them resistant to radiation.

Field funneling in SSBD's is the extension of the electric field along the ion track, beyond the depletion region. This field funneling can be observed by the measurement of the charge collected from ions of known energy and range (penetration distance) as a function of detector bias. Differential-capacitance measurements yield the depletion width as a function of the bias potential. The

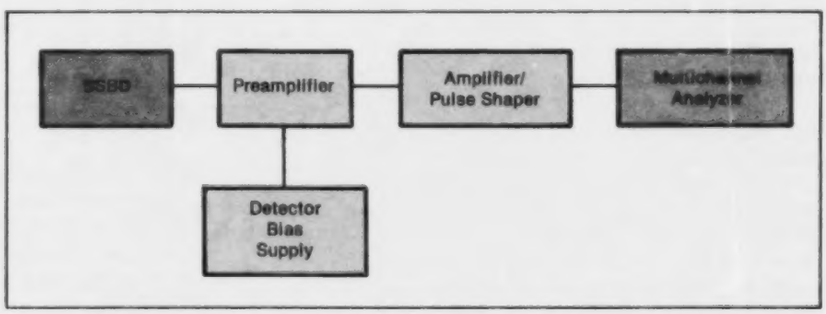

Figure 1. **Field Funneling and Range Straggling** are measured with the electronic system shown above, in which charge collected from individual ions is measured and recorded by the multichannel analyzer.

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generated charge is fully collected, even when the depletion width is somewhat less than the ion range. However, as the depletion width is diminished further (by lowering the detector bias) beyond a certain point, the narrow collected-charge (energy) peak in the energy spectrum of a beam of ions begins to decrease in amplitude and to be dispersed in energy.

Under these narrow-depletion-width conditions, the end-of-range charge is being collected by diffusion rather than by a drift field. Because diffusion is isotropic some of the charge is lost (observed as a decrease in signal amplitude), and the charge collected from individual ions is dispersed by range straggling, which is a variation in the distance traveled by individual ions, manifesting itself as dispersion in the energy spectrum.

To measure the funnel length, (the distance the electric field extends beyond the depletion region along the ion track) and to observe the dispersion of charge collection due to range straggling, data were obtained by collecting 8.78-MeV alpha particles from a Th^{228} emitter in an Au/N-type Si SSBD, using the electronic system of Figure 1. The charge collected from individual ions was measured and recorded by the multichannel analyzer. As the particles were counted, the number of counts within the energy-range intervals were recorded and displayed.

The top of Figure 2 shows the complete alpha-particle emission spectrum at a bias of 58 V. In this case, the depletion width, W, was 61 μm, which was greater than the 59 μm range of the most-penetrating 8.78-MeV alpha particles in Si. Therefore, all of the ionization charge was collected.

When the bias was 30 V, the depletion width of 44 μm was 15 μm less than the range. Since the peak was not appreciably lowered or dispersed, little or no charge was lost from the 15 μm portion of the ion track beyond the original depletion range. Consequently, the electric field must have been extended by that distance, which thus represents the funnel length for the 8.78-MeV alpha particles at a bias of 30 V.

When the bias was reduced to 20 V so that the depletion width was 36 μm, the 8.78-MeV peak moved lower on the energy axis by an amount equivalent to $\delta E = 0.21$ MeV. The energy spread of this peak increased to $\Delta E = 0.4$ MeV. The spectrum taken at a bias of 11 V shows the further decrease in the collected charge. The value of δE represents the amount of charge lost at the end of the ion track, because of diffusion away from the Schottky barrier. The energy dispersion, ΔE, reflects range straggling at the end of the ion track.

This type of data clearly indicates the roles of field funneling and range straggling in the collection of charge from ion tracks in Si solid-state devices. This technique is superior to that of observing individual-particle responses (i.e., output voltage as a function of time), because the individual tracks exhibit different charge losses by diffusion due to range straggling.

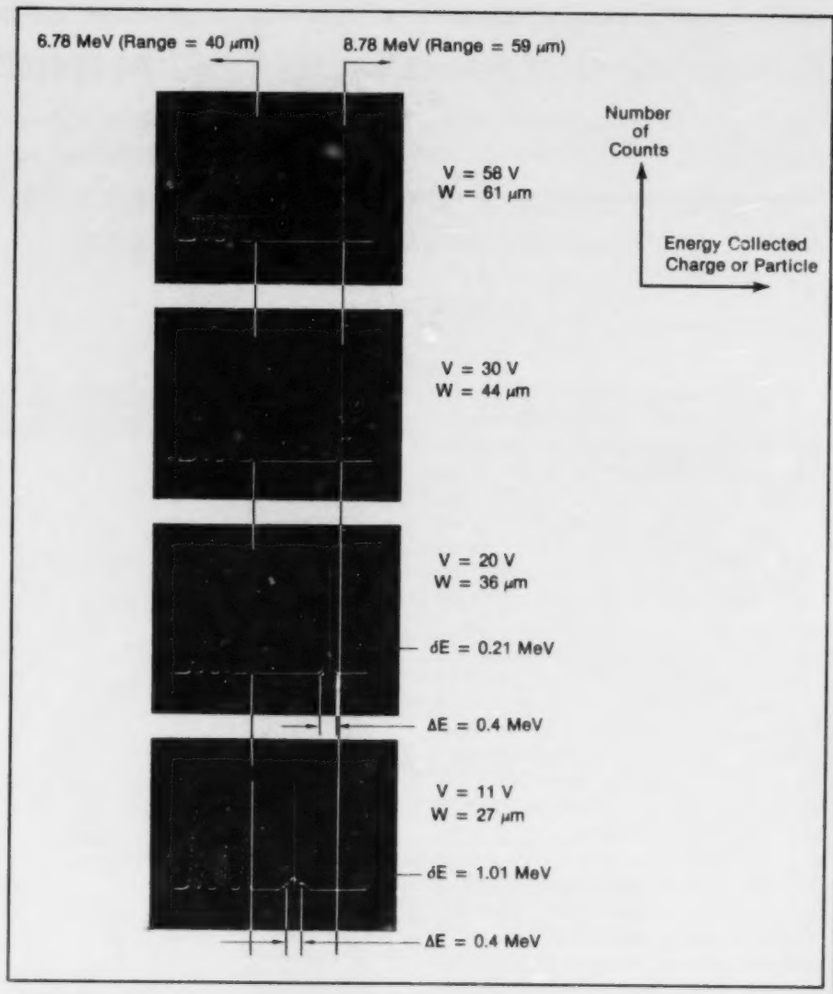
6.78 MeV (Range = 40 μm)
8.78 MeV (Range = 59 μm)
Number of Counts
Energy Collected Charge or Particle
V = 58 V
W = 61 μm
V = 30 V
W = 44 μm
V = 20 V
W = 36 μm
δE = 0.21 MeV
ΔE = 0.4 MeV
V = 11 V
W = 27 μm
δE = 1.01 MeV
ΔE = 0.4 MeV

Figure 2. **Charge-Collection Data** are shown as energy spectra of particles in an Si SSBD under different bias potentials.

This work was done by John A. Zoutendyk and Carl J. Malone of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 71 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA's Resident Office-JPL [see page 29]. Refer to NPO-16584.

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Estimating Microwave Delay by Atmospheric Water

This algorithm accommodates changes in the observation conditions, the emission model, and radiometer hardware.

NASA's Jet Propulsion Laboratory, Pasadena, California

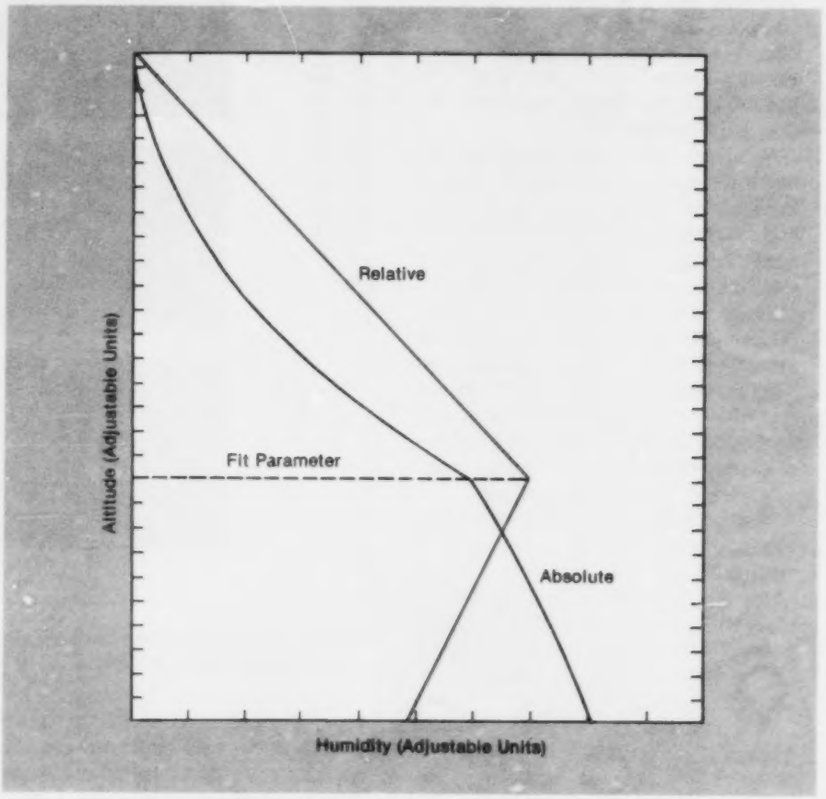
Tropospheric path delays for microwave very-long-baseline interferometry (VLBI) are estimated with an algorithm that determines and then explicitly integrates a simple water-vapor distribution based on temperature data from a water-vapor radiometer (WVR) and an emission model. Although computationally complex, this method readily accommodates even dramatic changes in observation conditions, the emission model, and the WVR equipment.

One of the most intractable error sources for microwave VLBI is tropospheric water vapor, which can contribute up to 30 cm of excess zenith delay. Because the water distribution varies strongly with time, the surface location, and the altitude, surface meteorology alone does not yield tropospheric models capable of producing the desired 0.5-cm accuracy. Consequently, as part of the calculation of wet-path delays, many VLBI observers now infer water distributions from data obtained by WVR's, which usually detect thermal emission at two frequencies near the 22-GHz rotational transition of water.

The new algorithm yields an optimized simple humidity-versus-altitude profile (see figure) that is the product of two functions, the first of which consists of the vapor pressure of the water normalized by the total pressure as a function of altitude. The second function, which specifies the vertical profile of the relative humidity, is defined in altitude by linearly connecting values at three altitudes.

At the surface of the Earth, the relative humidity is provided by surface meteorology, and at some high altitude, usually 10 km, the relative humidity can be taken as zero. The third point is an intermediate altitude around 2 km, where the relative humidity is estimated by the algorithm. Once the values at the three altitudes are known, the vapor profile is considered to be completely specified. The liquid-water profile, which normally has a much smaller effect, is assumed to be proportional to the vapor profile.

The actual vertical water distribution may be somewhat different from that specified by the profiles. However, in integrating the vapor distribution with other factors to calculate the wet delay, vapor-distribution variations of high spatial frequency average out, making a smooth function (that is, the profiles) an adequate representation.



A Simple Humidity-Versus-Altitude Profile obtained from surface meteorology, water-vapor radiometer temperature data, and the assumption of zero humidity above a certain elevation, is integrated with other factors when calculating the portion of the microwave signal-path delay due to water in the atmosphere.

Because the algorithm first establishes the profile parameters instead of proceeding directly to the delay, the mean height of the water-vapor distribution is effectively varied to make a best fit to the data. This allows for variations in the emission characteristics that arise from changes in the vertical distribution of the water. Therefore, the accuracy of the profile algorithm is not strongly influenced by site and seasonal variations. In addition, the necessary incorporation of a tropospheric-emission model into the formulation gives the ability to prescribe all parameters describing the WVR configuration and delay integrals with minimal effort for any data set. The price paid for these advantages is an increase in complexity and added computation time.

Simulations using radiosonde data from a number of locations show that intrinsic accuracy of the algorithm is better than 2 mm in clear weather. This level of error is competitive with the most accurate of the more conventional linear algorithms, which use retrieval coefficients tailored to specific sites.

This work was done by Steven E. Robinson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 31 on the TSP Request Card.*
NPO-16642

Measuring Sodium Chloride Contents of Aerosols

Particle analysis by mass spectrometry enables mass measurements of individual aerosol particles in real time.

NASA's Jet Propulsion Laboratory, Pasadena, California

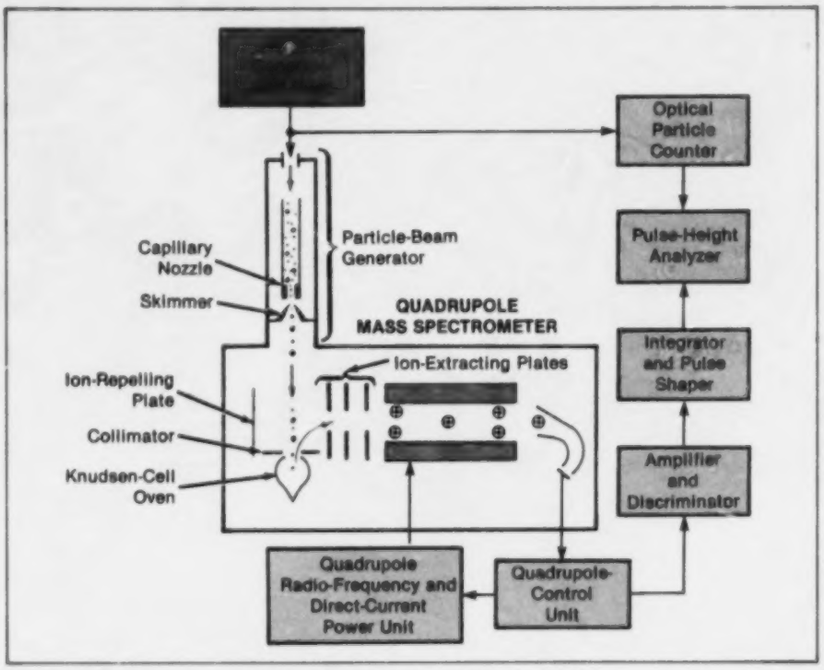
The amount of sodium chloride in individual aerosol particles can be measured in real time by an analyzer that includes a mass spectrometer. The analyzer can be used to determine the mass distributions of active agents in therapeutic or diagnostic aerosols derived from saline solutions and in analyzing ocean spray.

A beam of aerosol particles is formed by expanding the aerosol through a capillary nozzle into the vacuum in a particle-beam generator (see figure). The region between the nozzle and the skimmer is differentially pumped.

The particles in the beam are individually introduced into a miniature Knudsen-cell oven at 1,600 K. The oven, made from rhenium sheet 0.018 mm thick, is situated inside the ion source of a quadrupole mass spectrometer. Once inside the oven, a particle is trapped and completely vaporized. This is an improvement over conventional filament sources, in which particles bounce off the filaments and, therefore, are only partially vaporized.

The oven is located 6 cm downstream from the particle-beam generator. At this position, the particle beam is wider than the 1.50-mm-diameter oven opening. Particles in the outer ring of the beam striking the outside surface of the oven are likely to be only partially vaporized and, therefore, would cause errors in the measurements. Accordingly, a collimator is placed at the oven orifice. Particles hitting the collimator are reflected without appreciable vaporization or ionization and are therefore not analyzed.

Some of the atoms in the vapor are ionized. Each vaporized particle thus produces a pulse of ions that effuses out of the oven through the same opening by which the particles entered. The ions are swept into the quadrupole mass spectrometer, which is set to measure the intensities of the sodium-ion components of the vapor pulses. It has been determined by measurements that the sodium-ion-pulse amplitude is proportional to the mass of the vaporized salt particle raised to the 0.86 power.



Aerosol Particles Composed of Sodium Chloride are introduced into an oven, where they are individually vaporized on the hot wall. The vapor molecules are thermally dissociated, and some of the resulting sodium atoms are ionized on the wall. These ions leave the oven in a burst and are analyzed by the spectrometer, which is set to monitor the sodium-ion intensity.

This work was done by Mahadeva P. Sinha and Sheldon K. Friedlander of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 95 on the TSP Request Card.*
NPO-16722

Quiet Plasma Source

Synthesis of plasma from separate ion and electron emitters suppresses electromagnetic interference.

NASA's Jet Propulsion Laboratory, Pasadena, California

A plasma source operates at low pressure and generates little or no electromagnetic interference. The peak plasma density is 2×10^6 particles per cubic centimeter, and the background natural pressure is less than 10^{-5} torr ($\sim 10^{-3}$ N/m^2). Previously, plasma sources have utilized impact-ionization-discharges in neutral gases to produce ions and electrons. Such discharge sources generate a high level of electromagnetic interference and must use differential pumping to reduce the pressure of the neutral gas.

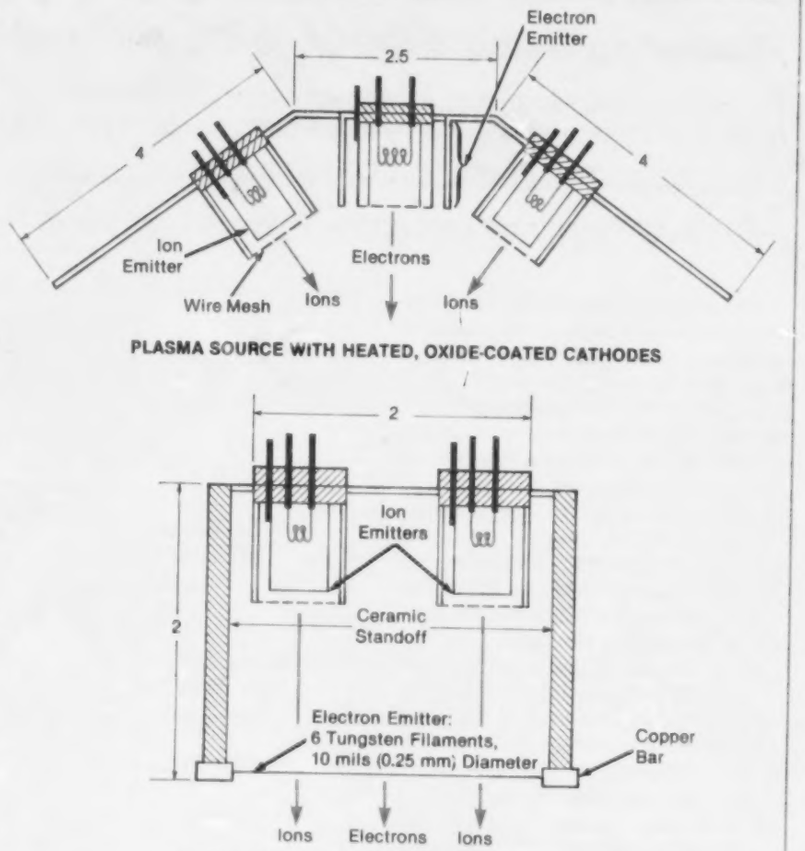
The new source (see figure) employs separate emitters for electrons and ions. The ion emitter is a β-eucryptite ($Li_2O \cdot Al_2O_3 \cdot 2SiO_2$) source that yields lithium ions without a gaseous electrical

discharge. The potential difference between the grid and the case controls the ion current. The ion energy is determined by the potential of the case with respect to ground.

The electrons are emitted by a grounded, conventional oxide-coated cathode or by tungsten filaments. In either case, the positive space potential created by the ions increases the electron emission by a factor of 5 to 10 so that the plasma density is high. The electron temperature is the same as the cathode temperature. Relatively cold electrons are needed for the original application of the plasma source — studying the effects of plasmas on high-voltage solar arrays. Consequently, the oxide cathode temperature was set at 1,460 °C (0.15 eV). The tungsten filaments produce electrons of higher temperature — about 3 eV. The higher temperature is attributed to the voltage drop along the filaments.

The plasma source can be used to simulate a variety of astrophysical phenomena and space-plasma effects. For example, it can be used in studies of the propagation of electromagnetic waves in plasmas. It can also serve as an interference-free charge neutralizer.

This work was done by Philip L. Leung of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 25 on the TSP Request Card.*
NPO-16215



Ions and Electrons Are Generated Separately in the plasma synthesizer. Two alternative configurations are depicted — with electrons generated either by an oxide-coated cathode or by tungsten filaments. In either case, the ion source is β-eucryptite, a hexagonal crystalline lithium aluminum silicate mineral.

Measuring Combustion Advance in Solid Propellants

The propellant forms a dynamic part of capacitors.

NASA's Jet Propulsion Laboratory, Pasadena, California

A set of gauges on a solid-propellant rocket motor with an electrically insulating case measures the advance of the combustion front and the local erosion rates of the propellant and insulation. The data furnished by the gauges aid in motor design, failure analysis, and performance prediction. The technique is also useful in determining propellant uniformity and electrical properties of the exhaust plume. The gauges can be used both in flight and on the ground. The foil-gauge technique may also be useful in basic research on pulsed plasmas or the combustion of solids.

Each gauge consists of a small metal foil on the outside of the rocket motor case (see figure). Each gauge constitutes one electrode of a capacitor, while the combustion products constitute the other electrode. Since the flame in the motor cavity is extremely hot — 2,000 to 3,000 K — the gaseous combustion products are ionized and, therefore, electrically conductive.

An ac electrical signal is applied to the gases, which induce a voltage signal in the foil electrodes through the intervening dielectric media of the propellant and motor casing. The induced pulses become larger as the propellant (and eventually part of the insulator) is consumed, thereby reducing the dielectric thickness. The outputs of the electrodes thus provide a profile of the moving combustion front. The detail of the profile depends on the number and locations of electrodes applied to the case.

Each electrode is connected by a separate wire and by a resistor and ground wire to electronic monitoring circuitry. The resistors could be thin chips on the surface of the motor case. The wires can be either thin, twisted pairs or flat transmission lines. For further protection, these components can be covered by a thin layer of epoxy resin, which protects them and en-

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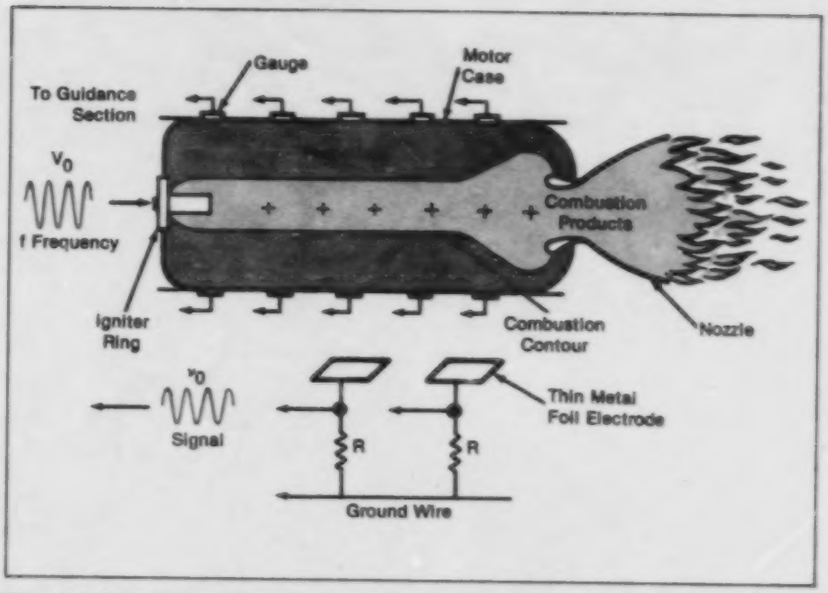
sures that they add only minimally to the aerodynamic resistance of the rocket.

Because the components are located outside the combustion chamber, they do not affect the combustion process. Preliminary estimates show that the amplitude of the applied voltage pulse can be made low enough so that it does not significantly perturb the combustion products.

If the motor case is made from electrically conductive materials, such as metals or carbon fiber composite, the electrodes can be placed inside the motor and insulated from the case. The gauge operates in a similar manner, except miniature cables are required for the gauge connection from the interior to the outside of the motor.

This work was done by Lien C. Yang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 6 on the TSP Request Card.*
NPO-16585



Metal-Foil Electrodes form capacitors with the plasma at the core of a motor engine, the propellant and motor case being the capacitor dielectric. Electrical pulses applied to the plasma thus appear on the electrodes.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Determining Monthly Mean Humidities From Satellite Data

Radiometric measurements over oceans are analyzed statistically.

A report describes a statistical study to estimate the monthly average humidity of the marine surface layer of the atmosphere from measurements by radiometers on satellites. The study is part of a continuing effort to determine the flux density of the latent heat due to evaporation at the ocean surface. Such observations and measurements are important because the latent-heat flux affects the weather and the temperature and salinity of the upper ocean layers.

The temperature and humidity of the atmospheric layer in contact with the ocean affect the exchanges of heat and momentum between the ocean and the atmosphere. The flux density, E, of water vapor can be estimated by the bulk parameterization formula: $E = \rho C_E U(Q_S - Q)$, where ρ is the density of the surface air, C_E is the transfer coefficient, Q_S is the saturation humidity at the surface temperature of the sea, U is the windspeed, and Q is the specific humidity. (U and Q are measured at a reference altitude near the surface.) The latent heat flux can be determined by multiplying E by the latent heat of vaporization L. The objective of this study is to determine Q.

At present, the number of meteorological reports from merchant ships and fishing vessels over vast areas of the equatorial and southern oceans are only adequate to determine the long-term averages; satellite data are needed to generate the evolving monthly averages over these areas.

A radiometer measurement gives the total amount of water vapor in the vertical atmospheric column under observation. In this investigation, mid-ocean vertical humidity distributions measured by radiosondes were statistically surveyed for correlations between the surface humidity and the total precipitable water content as measured by spaceborne radiometers.

The radiosonde soundings showed that Q can be estimated with an accuracy of 0.4 g/kg by applying a local statistical regression to a satellite observation. With a global regression, Q can be estimated within about 0.8 g/kg. These accuracies correspond to about 10 and 20 W/m^2, respectively, in the flux density of latent heat as determined by the bulk parameterization method, provided that the parameters other than humidity are also known.

This work was done by Wing-Yuen T. Liu and Pearn P. Niiler of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Determination of Monthly Mean Humidity in the Atmospheric Surface Layer Over Oceans From Satellite Data," Circle 116 on the TSP Request Card.*
NPO-16529

Reflective Shields for Artificial Satellites

Mirror facets would disperse radiant energy in many directions.

A report proposes a reflective shield that would protect a spacecraft from radiant energy. It would also give some protection against particle beams and cosmic rays.

The conceptual shield is essentially an advanced version of the decorative multifaceted mirror balls that are often hung over dance floors. A portion of a spheri-

cal surface — usually a hemisphere or an entire sphere — would be covered with flat, second-surface mirrors, each about 1 to 2 in. (2.5 to 5 cm) square. Because the number of facets is large and each faces in a different direction, there is only a small probability that incident visible or microwave radiation would be specularly reflected back to the signal source.

Each mirror segment would be made of fused borosilicate or fused aluminosilicate glass of a type previously developed for the mirrors of solar-energy systems. The glass would be about 0.040 to 0.06 in. (1.0 to 1.5 mm) thick, with high specularity and minimal diffuse reflectance or reradiation. The rear surface would be coated with a reflective layer of silver and copper, followed by a special backing paint. It is expected that such a mirror facet would reflect 96 to 98 percent of the incident solar electromagnetic energy; the remainder would be absorbed in the glass and metal layers.

The spherical shield support would preferably be made of aluminum; such alternatives as titanium, coated steel, or coated composites might also be used. A layer of acrylate, polycarbonate, or polyimide would be bolted or riveted onto the support to serve as a substrate for the mirror facets. The facets would be attached to the polymer substrate with a semirigid adhesive that allows for differences in thermal expansion. The spaces between facets would be filled with a sealant of butyl rubber with an outer layer of silicone that has been blackened to prevent reflections from the facet edges. Such a sealant also protects against ultraviolet, water vapor, and other environmental effects.

The shield can be mounted on hinges or other mechanisms to move it into place for different operating modes; for example, a spherical shield might be made in two hemispherical parts that are brought together to protect the satellite in all directions and moved apart to allow the satellite to communicate with other satellites or with ground stations. The shield could be a single hemisphere (or slightly more than a hemisphere) that protects the satellite from radiation from the ground, while allowing it to communicate with satellites in higher orbits. In this case, the entire satellite or the shield could be rotated to protect against radiation from above, while allowing communication with the ground.

This work was done by Frank L. Bouquet of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Energy Reflecting Spacecraft Shield and Concealment System," Circle 2 on the TSP Request Card.*
NPO-16428

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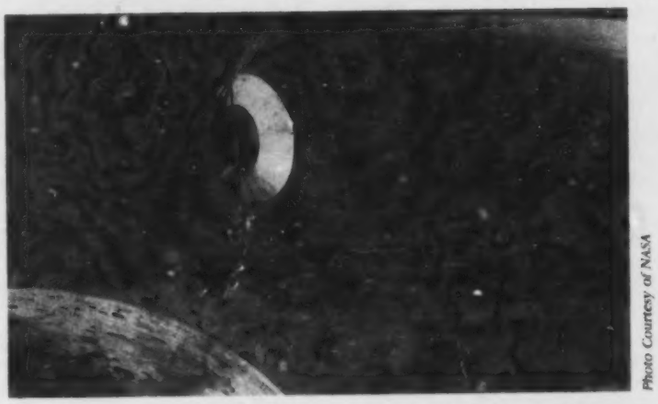

Photo Courtesy of NASA

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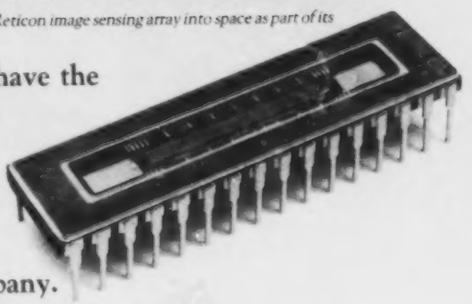

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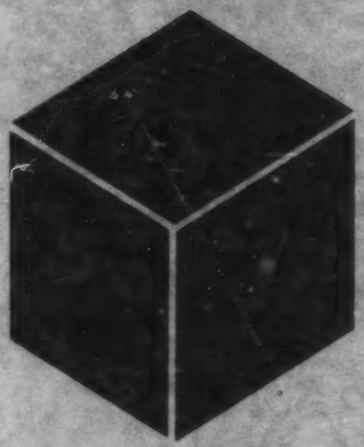

Hardware, Techniques, and Processes

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Lightweight, Fire-Resistant Graphite Composites

Paneling for aircraft interiors could be made safer.

Ames Research Center, Moffett Field, California

Aircraft safety could be improved with interior paneling made of a new laminate with good thermophysical properties. Featuring a lightweight graphite composite, the laminate is more heat- and flame-resistant and produces much less smoke in fire than the commonly used epoxy-resin-containing laminates.

In current paneling, an epoxy-resin-preimpregnated bond ply serves to bind the outer glass/polyvinyl fluoride decorative laminate to a honeycomb core. Upon exposure to fire or heat, the polyvinylfluoride and the glass/epoxy-resin substrate yield large quantities of smoke, a particular hazard in the close confines of an aircraft.

The new laminate (see figure) is prepared without the epoxy resin. A graphite unidirectional cloth is preimpregnated with a blend of vinyl polystyryl pyridine and bismaleimide (VPSP-BMI). Either of two types of VPSP-BMI blend is used, depending on the method of preparation of the chemicals and the technique used to fabricate the panel. For use in the hot-melt method, VPSP (30 parts by weight) might be mixed with BMI (70 parts by weight) and tetrahydrofuran (10 parts by weight). The graphite fiber is coated by a conventional hot-melt method at 70 °C, then dried at 80 °C.

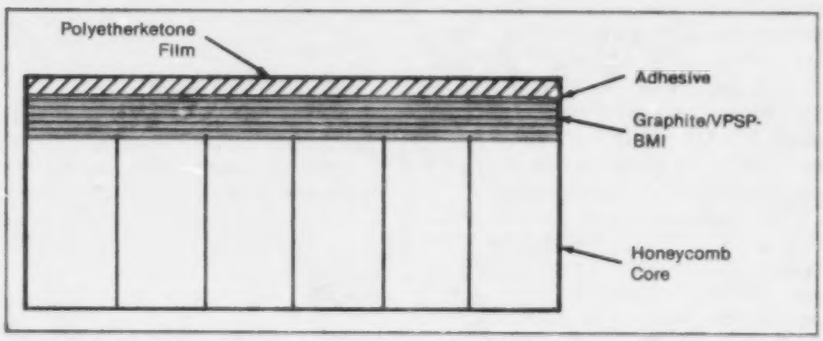
In the wet method, the resin proportions are the same, but 70 to 150 parts of tetrahydrofuran are used to obtain a solution with a suitably low viscosity. The graphite cloth is passed through the solution, then led between a steel roller and a wiper blade to assist impregnation and remove the excess solution. In both the hot-melt and wet methods, the impregnated cloth is stored in a plastic bag at −10 to 5 °C.

The impregnated cloth is cured at 180 °C and 100 psi (0.69 MPa) for about 1 hour; this curing schedule can be varied somewhat to suit the fabrication method. A decorative polyetherketone film can be applied with a polyamide or silicone adhesive. The laminate is joined to the honeycomb core with a pressure of 100 psi at 177 °C.

Composite panels 1 in. (2.5 cm) thick made in this manner have a density of 75 to 85 kg/m^3, which is 20 to 25 percent less than the density of panels made from the conventional epoxy/glass composites. In addition, the new laminates have processing and curing parameters comparable to those of the epoxy/glass composites, making their manufacturing costs lower than those of such other high-temperature- and fire-resistant resins as the polyimides.

This work was done by Demetrius A. Kourtides and John A. Parker of **Ames Research Center** *and Ming-Ta-Hsu of H.C. Chemical Corp. For further information, Circle 42 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11615.



An **Aircraft Panel** is made with the graphite/VPSP-BMI laminate on a honeycomb core. The graphite/VPSP-BMI is safer than epoxy/glass-fiber laminates because when heated it emits less smoke.

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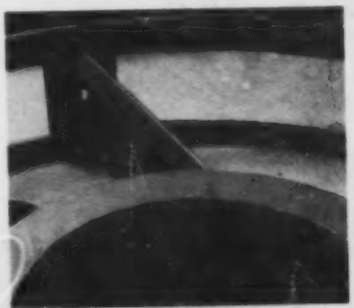

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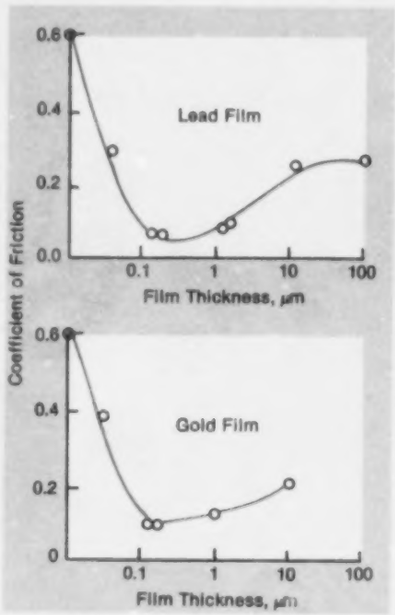
Ion-Plated Soft Metallic Films Reduce Friction and Wear

Self-lubricating surfaces protect sliding and rotating parts.

Lewis Research Center, Cleveland, Ohio

Ion plating is an ion-assisted or glow-discharge surface-deposition technique. In this process, ions or energetic atoms transfer energy, momentum, and charge to the substrate and the deposited surface film. This process can be controlled to modify the physical characteristics of the surface, the subsurface chemical conditions, and the surface and subsurface microstructures as well. Ion plating with such soft, thin metallic films as gold, silver, or lead has great potential for producing self-contained lubricating surfaces. Such films can reduce friction, wear, and corrosion on sliding or rotating mechanical surfaces used in a wide range of environments.

The difference between the ion-deposited surface and the substrate results in a gradient interface. The graded interface not only guarantees an excellent adherence but also induces a surface-strengthening effect which improves the mechanical properties, such as tensile and fatigue strengths. These ion-plated films, unlike the more conventionally formed films, are normally very thin (about 0.2 μm) and exhibit distinct, improved film structures with equiaxed, small grains, which are responsible for the high density and a minimum degree of lattice misfit. As a result, continuous, uniform films are obtained at lower nominal thicknesses, which have a favorable effect on the coefficient of friction, as shown in the figure for the gold and lead films. The minimum critical film thickness is responsible for the lowest coefficient of friction and decreased steady-wear rate.



The **Coefficient of Friction** varies with the thicknesses of the ion-plated films.

The frictional and wear behavior is correlated with the coating structure and the coating/substrate adherence. Consequently, three distinct improvements exist over the conventionally deposited films: (1) increased endurance life, (2) lower coefficient of friction and reduced wear, and (3) the avoidance of catastrophic failure after film depletion. Much additional work remains to be done in the field, and vast improvements in surface properties are possible in the future.

This work was done by Talivaldis Spalvins of **Lewis Research Center.** *Further information may be found in NASA TM-87055 [N85-29085/NSP], "The Structure of Ion Plated Films in Relation to Coating Properties."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14311

Detecting Pores in SiC Coatings

A nondestructive testing method produces images of inadequately covered areas.

Lyndon B. Johnson Space Center, Houston, Texas

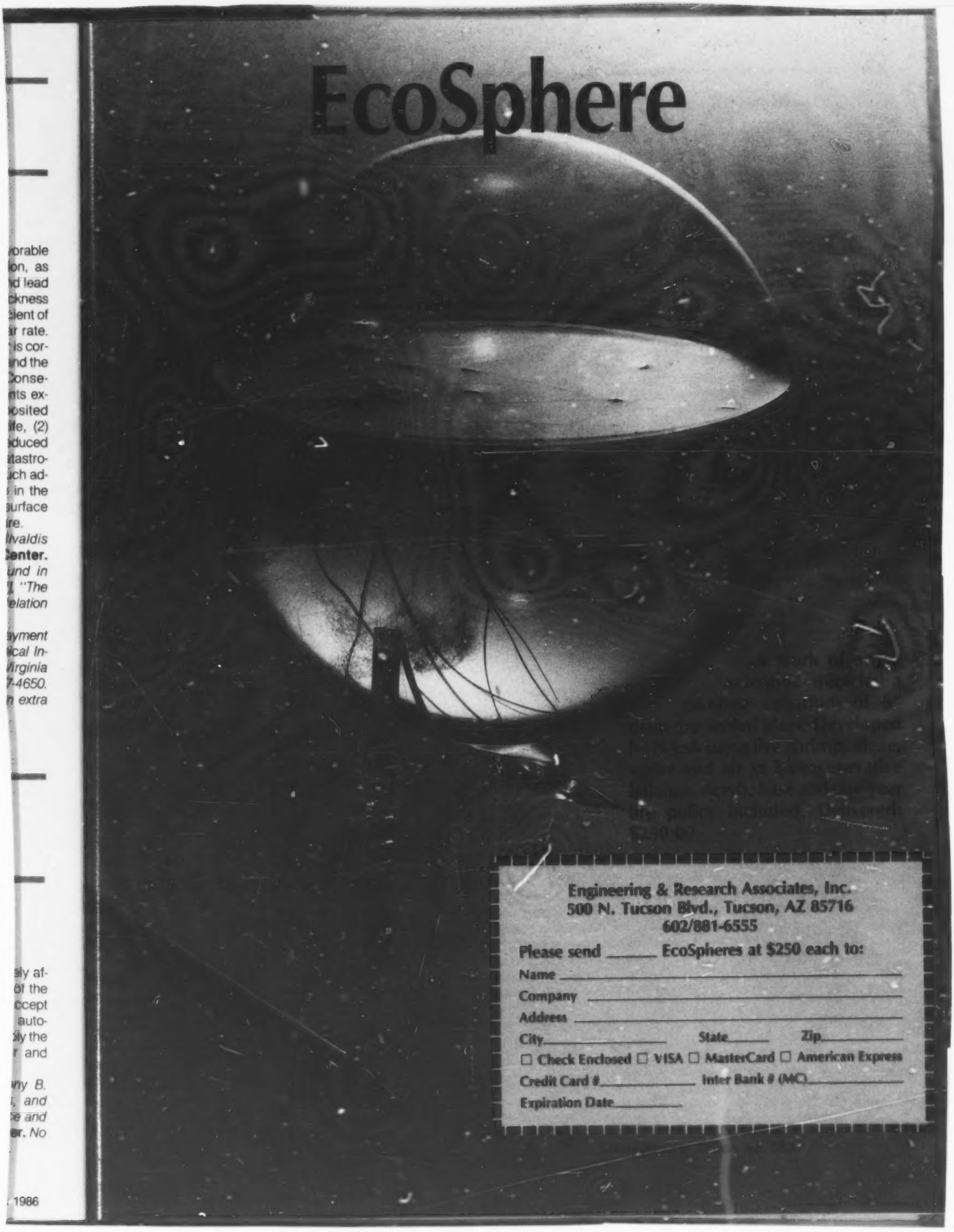
A liquid-penetrant/fluorescence technique reveals cracks and pinholes in protective coatings. The technique was developed for checking the quality of overcoatings on silicon carbide layers on advanced carbon/carbon substrates. The difference in thermal expansion rates between the substrate and the silicon carbide tends to crack the silicon carbide layer. The silicon carbide coating prevents the exposed substrate from oxidizing, but the effectiveness of the coating is greatly reduced if it is cracked or porous.

The new technique is similar to other liquid-penetrant/fluorescence techniques used to make pores visible. If porosity is excessive, the material can be recoated or perhaps subjected to a healing process that would close the pores.

The penetrant is a suspension of organic fluorescent particles, 3 to 50 μm in diameter, in isopropyl alcohol. The part can be dipped in the suspension, or the suspension can be brushed or poured on the part. After about 5 min, the part is viewed in ultraviolet light. Porous areas absorb more of the suspension and therefore accumulate more fluorescent particles. They therefore fluoresce more brightly than their surroundings.

The absorption does not adversely affect the protective characteristics of the coating or the ability of the part to accept a recoat. The technique could be automated by using spray nozzles to apply the suspension and a scanning laser and photodetectors to find the pores.

This work was done by Anthony B. Hamilton, Kenneth L. Tummons, and James W. Lawton of LTV Aerospace and Defense for **Johnson Space Center.** *No further documentation is available.*
MSC-21041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Chemical Fracturing of Refractory-Metal Vessels

Localized reactions could cause refractory-metal vessels to break up at predetermined temperatures.

NASA's Jet Propulsion Laboratory, Pasadena, California

A concept that might assist in the breaking-up of nuclear reactors of spacecraft power systems upon re-entry into the atmosphere could be used in safety devices that would disintegrate whenever the temperature exceeds a predetermined value. A device following this concept can be designed to break up along predetermined lines into smaller pieces at a temperature significantly below the melting point of the metal from which it is made. Possible applications may include fire extinguishers that could breakup to release extinguishing gas in enclosed areas, pressure vessels that could otherwise burst dangerously in fire, and self-destroying devices. The technique is particularly suitable as a modification to already existing structures.

Current nuclear power systems of spacecraft are constructed of such relatively low-melting-temperature materials as stainless steel (melting point about 1,800 K). Advanced power systems that are now being developed include materials that require dispersion and are encased by walls made of such refractory metals as tungsten, molybdenum, niobium, or tantalum. The melting points of these metals range from 2,740 to 3,680 K. Such temperatures cannot be reached easily by aerodynamic heating alone.

According to the new concept, tubes containing a metal or an oxidizing agent would be welded into the walls along the desired lines of failure. The metal or oxidizing agent would be solid and nonreactive at normal reactor temperatures. When heated above the designated failure temperature, the material in the tubes would react rapidly with the refractory metal to form a liquid alloy or oxide. The walls of the vessel would thereby be liquefied and parted at the tube locations, causing the vessel to break up and its content to be dispersed.

For example, niobium tubes filled with beryllium could be welded to niobium vessel walls. During normal service, the reactor might operate at 1,100 K, which is more than 500 K below the beryllium melting point and 1,640 K below the niobium melting point (2,740 K). However, when the temperature approaches the beryllium melting point, the beryllium begins to alloy with the niobium tube to form a liquid along the line of the tube. (A 90Nb/10Be alloy melts at 1,873 K.) Alternatively, the tubes could contain an oxidizing agent like WO_3 or V_2O_4, which would melt and oxidize the Nb to Nb_2O_5 (melting point 1,785 K).

This work was done by Robert J. Campana of GA Technologies Inc., for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 13 on the TSP Request Card.*
NPO-16541

Abrasion-Resistant Coating for Flexible Insulation

A two-step process increases the ruggedness of fragile quartz fabric.

Lyndon B. Johnson Space Center, Houston, Texas

A ceramic coating increases the durability and heat resistance of flexible high-temperature insulation. The coating is compatible with the quartz-fabric insulation and allows it to remain flexible during and after repeated exposures to temperatures of 1,800 °F (982 °C). It prevents the fabric from becoming brittle while increasing its resistance to aerodynamic abrasion and loading.

The coating consists of a penetrating precoat and a topcoat. The major ingredients are high-purity colloidal silica binder and ground silica filler, which ensure stability and compatibility with the fabric at high temperatures. The ratio of binder to filler must be carefully controlled to ensure erosion resistance. Also essential to erosion resistance is adhesion to the fabric; this is provided by the precoat, which penetrates the waterproofing on the fabric and interlocks with the fibers.

The precoat consists of a solution of 80 parts by volume of colloidal silica in 20 parts isopropyl alcohol. The ingredients are mixed by adding the alcohol to the silica while stirring.

The topcoat consists of a mixture of 47 percent by weight colloidal silica and 53 percent ground silica. The ingredients are mixed on a rolling mill in a porcelain grinding jar containing Alundum (or equivalent) aluminum-oxide pebbles. Both the precoat and the topcoat should be stored in sealed polyethylene containers. The materials have long shelf lives, provided that the precoat is agitated once per week and again just before use.

The precoat is brushed or sprayed on the fabric so as to coat it completely and uniformly. About 0.12 lb/ft^2 (0.59 kg/m^2) of precoat should be applied per 100 ft^2. It should be allowed to dry for at least 4 hours before the topcoat is applied.

The topcoat is similarly brushed or sprayed, with special care taken that the slurry is worked into the spaces between fibers. About 12 lb should be applied per 100 ft^2. The topcoat should be dried for 24 hours before the fabric is used. Both the precoat and topcoat can be cured at room temperature.

This work was done by Daniel Mui and Ronald E. Headding of Rockwell International Corp. for **Johnson Space Center.** *For further information, Circle 50 on the TSP Request Card.* *MSC-20799*

Polyimide of Modified Melt Flow and Toughness

End capping improves process-flow properties.

Langley Research Center, Hampton, Virginia

A linear aromatic polyphenylene ether sulfideimide (BDSDA/APB) polymer has been molded, used as a resin, and cast into thin films. According to recent experiments to synthesize and characterize this polymer, the polymer is well suited for processing by conventional thermoplastic methods. In an effort to improve further both the use properties and the amenability to process BDSDA/APB, the molecular weight of the polymer was varied by variations in the percentage of end capping. The effect of end capping BDSDA/APB was determined by the measurement of the polymer melt viscosity and fracture-energy values for the different number-average synthesized molecular weights.

When the ends of the molecules were capped with varying amounts of phthalic anhydride, the molecular weight of the polymer was lowered from 13,900 to 8,660. This decrease resulted in a concomitant decrease in the melt viscosity, as shown in Figure 1. At 250 °C there was no deviation from linearity, but at the higher extrusion temperature of 280 °C, the viscosity dropped steeply for polymers with molecular weights below 10,000. This information should prove valuable in optimizing the amenability of the polymer to processing.

When moldings were prepared from the polymers of different molecular weights, the fracture-energy values showed that a considerable loss in fracture resistance occurs as the molecular weight decreases; this is shown in Figure 2. Of particular interest was the fact that, over the range tested, the fracture energy was related linearly to the molecular weight.

When mixtures of the low and high molecular weight polymers were evaluated, it was found that the flow properties were controlled by the low molecular weight portion and the toughness (fracture energy) obeyed a simple rule of mixtures.

This approach of limiting molecular weight to improve the flow properties of BDSDA/APB has proven successful. From the results obtained concerning the variation of the melt viscosity and the fracture energy with the change in number-average molecular weight, it is obvious that tradeoffs can be made between process optimization and final mechanical properties, when polymer formulations are developed.

This work was done by Terry L. St. Clair and Harold D. Burks of **Langley Research Center**. *For further information,*

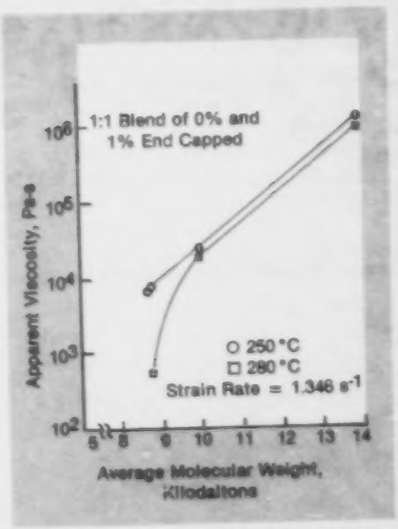

Figure 1. The **Viscosity of BDSDA/APB** increases with increasing average molecular weight; thus, end capping improves the flow characteristics in processing.

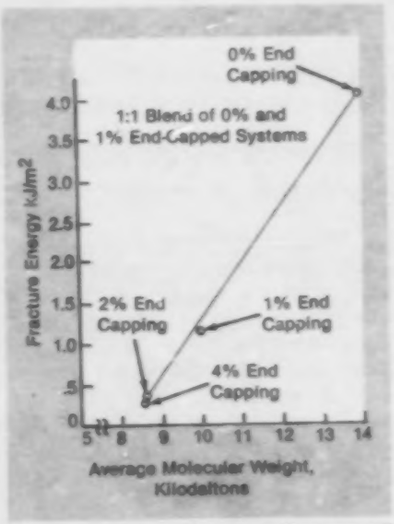

Figure 2. The **Fracture Energy of BDSDA/APB** increases with increasing average molecular weight; thus, end capping decreases the resistance to cracking.

Circle 68 on the TSP Request Card.

This invention has been patented by NASA (U.S. Patent No. 4,552,931). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13135.

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Batch Gas-Sampling System

Specimens are kept in a stable form until they can be recovered and examined.

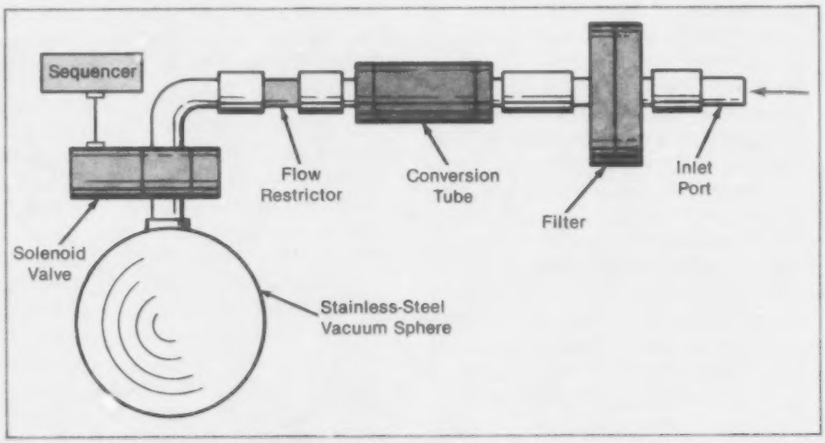
Lyndon B. Johnson Space Center, Houston, Texas

A sampler collects air or other gases in a consistent way and stabilizes them for later chemical analysis. The device can be used for concentrations ranging from a few parts per million to 100 percent. It also separates and collects particles in the gas for analysis.

The sampler is gas specific; that is, a separate sampler is needed for each component of the gas to be analyzed. Each sampler contains a material selected expressly to react irreversibly with a given component. The amount of the new compound thus formed is proportional to the concentration of the component in the sampled air. Because the new compound is inert, it can be stored in the sampler for long periods without deteriorating and causing an erroneous analysis.

To start the collection of a sample, a sequencer sends an electric current to a solenoid valve (see figure). The valve opens, and gas from the surroundings is immediately drawn by the vacuum in a stainless-steel sphere into an inlet port, where particles are trapped in a filter. The gas continues into a conversion tube, where the component of interest reacts and is changed into a stable compound in proportion to its concentration. At the end of a preset collection period or when the vacuum is exhausted, the sequencer closes the valve.

An attendant recovers the sample by removing, tagging, and sealing the conversion tube and the filter and sending them to a laboratory for analysis. The attendant evacuates the sphere with a vacuum pump and installs a new conversion tube and filter. The sampler is then ready to collect again.



Gas Flows Into a Vacuum Sphere when the solenoid valve is opened. As it passes through the conversion tube, a constituent of the gas forms a stable compound that remains in the conversion tube for analysis at a later time. The sampler parts are made of glass, polytetrafluoroethylene, and stainless steel so that they do not react with the sample.

The sequencer can be a microprocessor that operates an assembly of samplers on a programmed long- or short-term schedule. Alternatively, the valves can be operated manually. The assembly of samplers may be fixed or portable.

With a 500-milliliter capacity, each sphere on an assembly draws in the same volume of gas every time. If the velocity of the in-rushing gas affects measurement accuracy, it can be controlled by the configuration and size of the inlet port.

This work was done by Vernon Diaz, Jr., Eric L. Miller, and Fred P. Rollins of Lockheed Engineering and Management Services Co., Inc., for **Johnson Space Center.** *For further information, Circle 57 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-20977.

Producing Silicon Carbide/Silicon Nitride Fibers

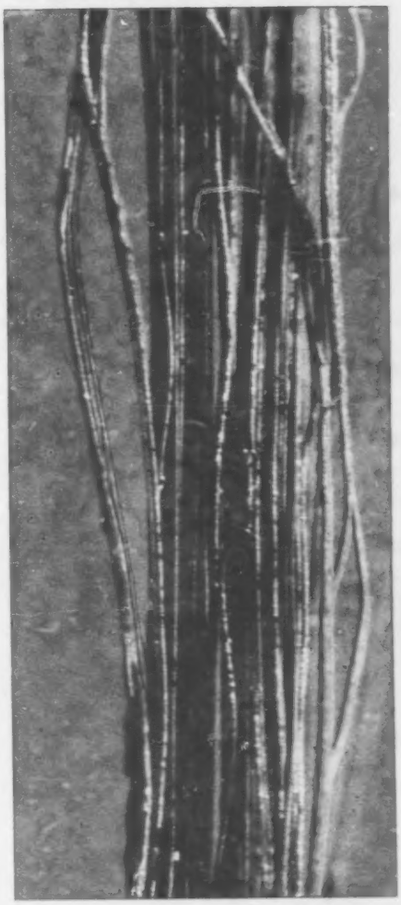
Promising reinforcement fibers for composites are made from extruded resin.

Marshall Space Flight Center, Alabama

An experimental manufacturing process makes $C_xSi_yN_z$ fibers. Precursor fibers are spun from an extruding machine charged with a polycarbosilazane resin. When pyrolyzed, the resin is converted to a cross-linked mixture of silicon carbide and silicon nitride, still in fiber form. The $C_xSi_yN_z$ fibers are promising substitutes for carbon fibers in high-strength, low-weight composites where high electrical conductivity is unwanted.

The extruding machine is basically a cylinder-and-piston assembly. A variable-speed dc motor, acting through a differential-screw mechanism, pushes the piston into the cylinder cavity at a controlled rate. The piston pushes hot resin from the cavity through fine holes in a plate at the end of the cavity. The resin emerges from the holes as continuous fibers, which are wound on a variable-speed takeup wheel. The fibers can be extruded directly into the air; a controlled-atmosphere cabinet is not needed.

In one of several experiments under various conditions, the machine extruded molten resin at 225 °F (107 °C) through a 32-mil (0.81-mm) orifice into fibers of 25 to 30 μm diameter. About 3,000 ft (900 m) of fiber were drawn on the takeup wheel



A **Bundle of Pyrolyzed Fibers** is composed mainly of cross-linked silicon carbide and silicon nitride molecules. Like carbon fibers, these $C_xSi_yN_z$ fibers can reinforce composite materials. However, $C_xSi_yN_z$ has higher electrical resistivity, and therefore may be usable where the lower resistivity of carbon cannot be tolerated.

in 3 minutes.

The fiber is crosslinked in a hydrolysis reaction: It is heated to 50 °C at 100 percent relative humidity for several days. During this time, the fiber strength and melting point increase, and its brittleness decreases. After 9 days, the softening temperature reaches 800 °C.

The crosslinked fiber is pyrolyzed to drive out the more-volatile organic components, leaving $C_xSi_yN_z$. In this process, fibers are gradually heated to 1,000 °C during 3 hours in a nitrogen atmosphere. The product (see figure) has a shiny, black metallic appearance.

This work was done by Bjorksten Research Laboratory, Inc., for **Marshall Space Flight Center.** *For further information, Circle 59 on the TSP Request Card.*

MFS-27123

Oxygen-Concentrating Cell

High-purity oxygen is produced electrolytically from breathing air.

John F. Kennedy Space Center, Florida

High-purity oxygen is produced from breathing air or from propellant-grade oxygen in an oxygen-concentrating cell. A full-scale concentrator having a total apparent electrode area of 27.9 m^2 would produce 5,606 kg per week. The operating economics of the concentrator are attractive: The energy consumption would be about 4 Wh per liter of oxygen, slightly lower than that of conventional electrochemical oxygen extractors.

The oxygen-concentrating cell operates by the reduction of oxygen in the feed gas flowing past the cathode, according to the reaction

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The hydroxide ions migrate through an asbestos matrix soaked with saturated potassium hydroxide electrolyte toward the anode, where the reverse reaction releases oxygen. Because of activation, diffusion, and ohmic losses, the bias voltage required for this process using breathing air is two orders of magnitude larger than the theoretical open-circuit value of 0.01 V calculated from the Nernst equation.

In an experimental version of the cell, the anode consisted of nickel cobalt oxide, 20 mg/cm^2, bonded with polytetrafluoroethylene on a gold-plated 100-mesh (wire diameter 0.11 mm) nickel screen. The cathode consisted of platinum black, 10 mg/cm^2, bonded with polytetrafluoroethylene on an identical screen. The asbestos matrix was 20 mils (0.5 mm) thick. The current collectors were made of perforated expanded-metal material (EXMET or equivalent), with a sheet thickness of 10 mils (0.25 mm) and a strand width of 58 mils (1.5 mm). The anodic current collectors were gold-plated to prevent oxidation. Silver wires were attached to the current collectors to serve as electrical leads out of the cell. The cell housing was made of acrylic plastic and sealed with a two-part epoxy

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resin.

The cell was operated with a dc power supply. To prevent electrode degradation, the bias was not allowed to exceed 1.2 V. To prevent the loss of electrolyte and carbonate poisoning of the electrodes, the feed gas was scrubbed with an alkaline solution before entering the cell. To eliminate CO_2 poisoning, experiments were conducted immediately after the addition of the electrolyte through the oxygen-collecting port.

Impedance measurements were taken as the bias voltage was increased incrementally from the minimum up to the maximum of 1.2 volts. Cathodic measurements were taken immediately after anodic measurements, and as soon as reasonably steady states were reached. Taken in 5-h runs, polarization measurements were repeatable. Taken in 12-h runs, measurements of oxygen purity showed a level of 99.996 percent.

This work was done by Kurt Buehler of **Kennedy Space Center**. *For further information, Circle 86 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 29]. Refer to KSC-11335.

Lubricants and Additives Affect Spur-Gear Fatigue

Additives increase gear life considerably.

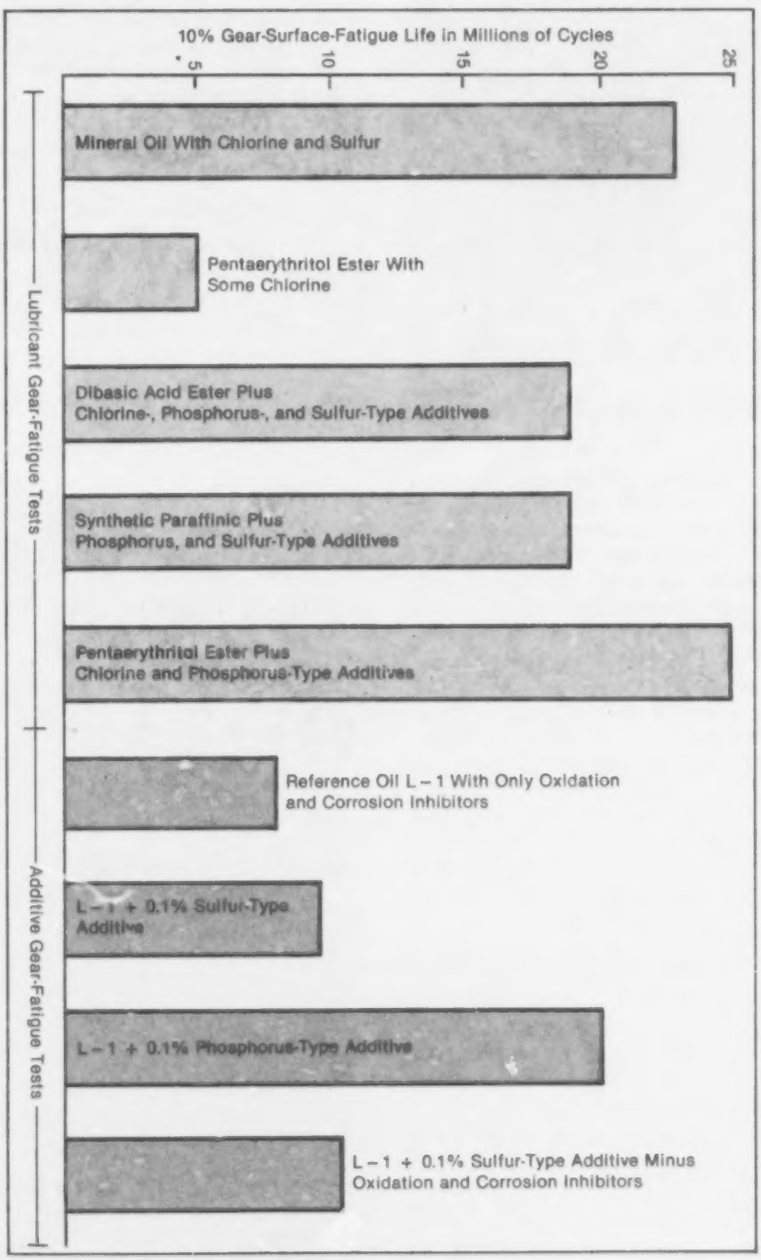
Lewis Research Center, Cleveland, Ohio

Surface-fatigue tests conducted with AISI 9310 steel spur gears have shown that the surface-fatigue life of AISI 9310 steel spur gears can be increased by as much as 400 percent by the addition of a small amount of a phosphorus-type extreme-pressure (EP) additive in the lubricant.

Research was conducted at the NASA Lewis Research Center to investigate the effects of lubricant base stock and additive content on the spur-gear surface-fatigue (pitting) life. Spur-gear endurance tests were conducted with six lubricants, using a single lot of AISI 9310 gear-test specimens. The sixth lubricant was divided into four batches, each of which had a different additive content. The lubricants used in the investigation can be classified into three basic types: synthetic hydrocarbon, mineral oil, and ester-based lubricants. The ester-based lubricants meet the MIL-L-23699 specification and were aircraft type II lubricants.

Gear failure by surface fatigue is affected by the physical and chemical properties of the lubricant. Lubricant additives are normally used in gear lubricants to increase the load-carrying capacity of the gears. The EP additives can prevent or minimize wear and surface damage (scoring) to gears when the load-carrying surfaces operate under very-thin-film or boundary-lubrication conditions. There are many gear systems that operate with this thin-film condition.

The antiwear or EP additives either are adsorbed onto the surface or react with the surface to form a protective coating or surface film. The boundary film provides a barrier that prevents contact of the metal surfaces and provides a low shear strength, which reduces the friction coefficient below that of the base metal.


10% Gear-Surface-Fatigue Life in Millions of Cycles
5
10
15
20
25
Lubricant Gear-Fatigue Tests
Additive Gear-Fatigue Tests
Mineral Oil With Chlorine and Sulfur
Pentaerythritol Ester With Some Chlorine
Dibasic Acid Ester Plus Chlorine-, Phosphorus-, and Sulfur-Type Additives
Synthetic Paraffinic Plus Phosphorus, and Sulfur-Type Additives
Pentaerythritol Ester Plus Chlorine and Phosphorus-Type Additives
Reference Oil L – 1 With Only Oxidation and Corrosion Inhibitors
L – 1 + 0.1% Sulfur-Type Additive
L – 1 + 0.1% Phosphorus-Type Additive
L – 1 + 0.1% Sulfur-Type Additive Minus Oxidation and Corrosion Inhibitors

The Surface-Fatigue Lives of AISI 9310 Gears were measured while using them with nine different lubricants.

A summary of the gear-test results is shown in the figure. One lubricant tested with a phosphorus-type EP additive showed a fatigue-life increase of 400 percent over a similar lubricant without this additive. EP and antiwear additives in the lubricant appear to control the resultant surface-fatigue life of the gears. The surface films were 200 to 400 Å (0.8 to 1.6 μin.) thick. These results reveal that the type II aircraft lubricants with phosphorus-type EP additive can produce fatigue-life results equivalent to those of mineral-oil lubricants formulated specifically for gear applications.

This work was done by H. W. Scibbe, D. P. Townsend, P. R. Aron, and E. V. Zaretsky of **Lewis Research Center**. *Further information may be found in:*

NASA TP-2408 [N85-13234/NSP] "Effect of Lubricant Extreme-Pressure Additives on Surface Fatigue Life of AISI 9310 Spur Gears,"

NASA TP-2419 [N85-16099/NSP], "Effect of Five Lubricants on Life of AISI 9310 Spur Gears," and

NASA TM-87044 [N85-28373/NSP], "Lubricant and Additive Effects on Spur Gear Fatigue Life."

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

LEW-14314

Polyimide Film of Increased Tear Strength

A new process incorporates an elastomer into the polymer to increase this strength.

Langley Research Center, Hampton, Virginia

A high-temperature linear aromatic polyimide with improved resistance to tearing is made by a new process that incorporates an elastomer into the polyimide. Linear aromatic condensation polyimides are materials of prime choice for use as films and coatings on advanced spacecraft and aircraft where durability at temperatures in the range of 200 to 300 °C is required. The tendency of these films to tear upon impact by meteors or other space debris limits their usefulness in space applications. It is anticipated that elastomer-containing polyimide film with improved toughness will prove useful for applications where resistance to tearing and long-term thermal stability are necessary.

The elastomeric phase is provided by the addition of an aromatic-amine-terminated butadiene/acrylonitrile (AATBN) rubber into the polyimide. The AATBN is dissolved with a diamine such as 4, 4′-oxydianiline in amide solvent. A dianhydride such as benzophenone tetracarboxylic dianhydride is then added to the mixture to produce an intermediate polyamic acid. In summary, the entire process involves the preparation of the amic acid prepolymer into which a specific amount of AATBN elastomer has been chemically reacted, the preparation of the elastomer-containing polyamic acid film, and the conversion of the film to the polyimide by heating at 250 °C.

The desired resistance to tearing is achieved by careful control of the amount and chemical composition of the added elastomer. The concentration of the AATBN in the elastomer-containing polyimide film is critical. Various samples prepared show that the tear strength of the film is at a maximum (a 50-percent improvement over the polymer containing no elastomer) when the concentration of the elastomer is 10 percent by weight of the polymer. At concentrations of 5 percent and 15 percent of elastomer, the tear strength is improved by approximately 25 percent. At a concentration of 20 percent AATBN, there is no improvement of tear strength at all.

The acrylonitrile content of the AATBN is also a critical factor. The three examples cited above had AATBN with 18 percent acrylonitrile content. A polymer system prepared with 15 percent AATBN having no acrylonitrile content produced the largest increase in tear strength (50 percent), while one having 10 percent acrylonitrile content produced very little increase in tear strength.

This work was done by Anne K. St. Clair and Jeffrey A. Hinkley of **Langley Research Center** *and Stephen A. Ezzell of Virginia Polytechnic Institute and State University. For further information, Circle 51 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 29]. Refer to LAR-13491.

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High-Temperature Alloys for Automotive Stirling Engines

Alloys are chosen for availability, performance, and manufacturability.

Lewis Research Center, Cleveland, Ohio

NASA and DOE have investigated the Stirling engine (see Figure 1) as an alternative to the internal-combustion engine. The Stirling engine is an external-combustion engine that offers fuel economy, low emissions, low noise, and low vibrations. One of the most critical areas in the engine development concerns material selection for component parts.

Alloys CG-27 and XF-818 have been identified after an extensive research program at NASA's Lewis Research Center to be capable of withstanding the rigorous requirements of the automotive Stirling engine. For potential mass production and customer satisfaction, alloys were required to be low in cost and to contain a minimum of such strategic materials as cobalt and chromium. Further requirements imposed on the heater-head alloys included good high-temperature strength, oxidation/corrosion resistance, compatibility with hydrogen and resistance to hydrogen permeation, capability to be fabricated, weldability, and long-term cycle operation.

Alloy CG-27 was chosen for the heater-head tubes because of its high strength (see Figure 2, top) achieved by precipitate strengthening and its resistance to hydrogen permeation achieved by forming an aluminum-rich oxide on the tube internal diameter (see Figure 2, middle). Alloy XF-818 was chosen for the cylinder

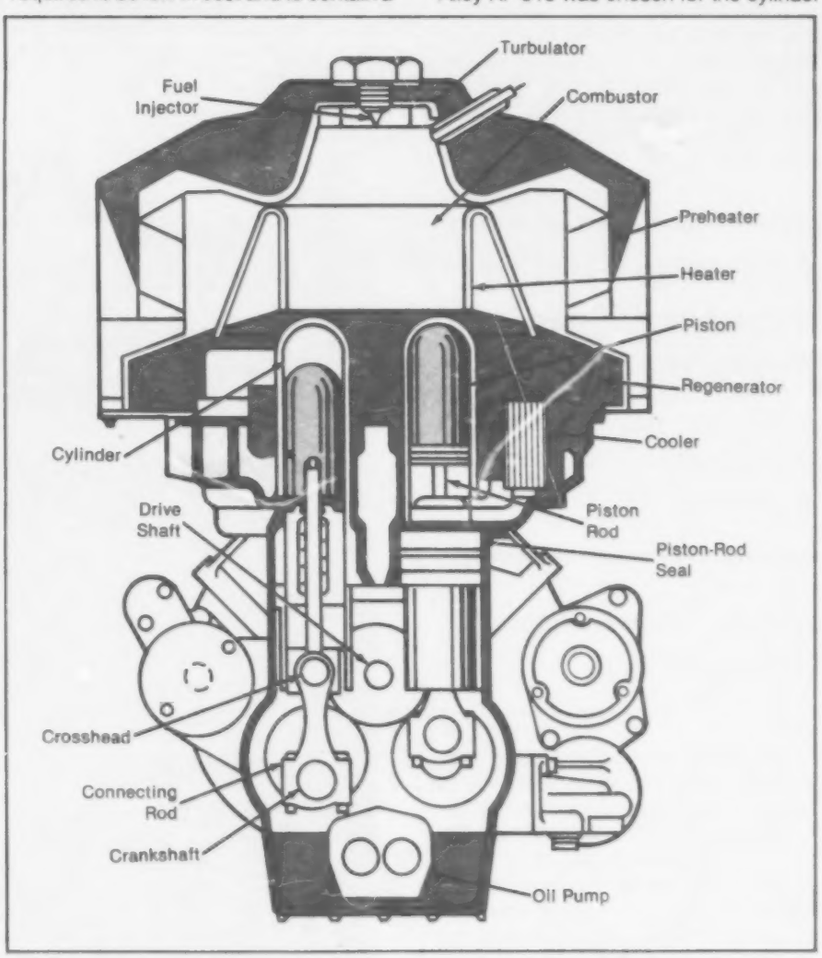
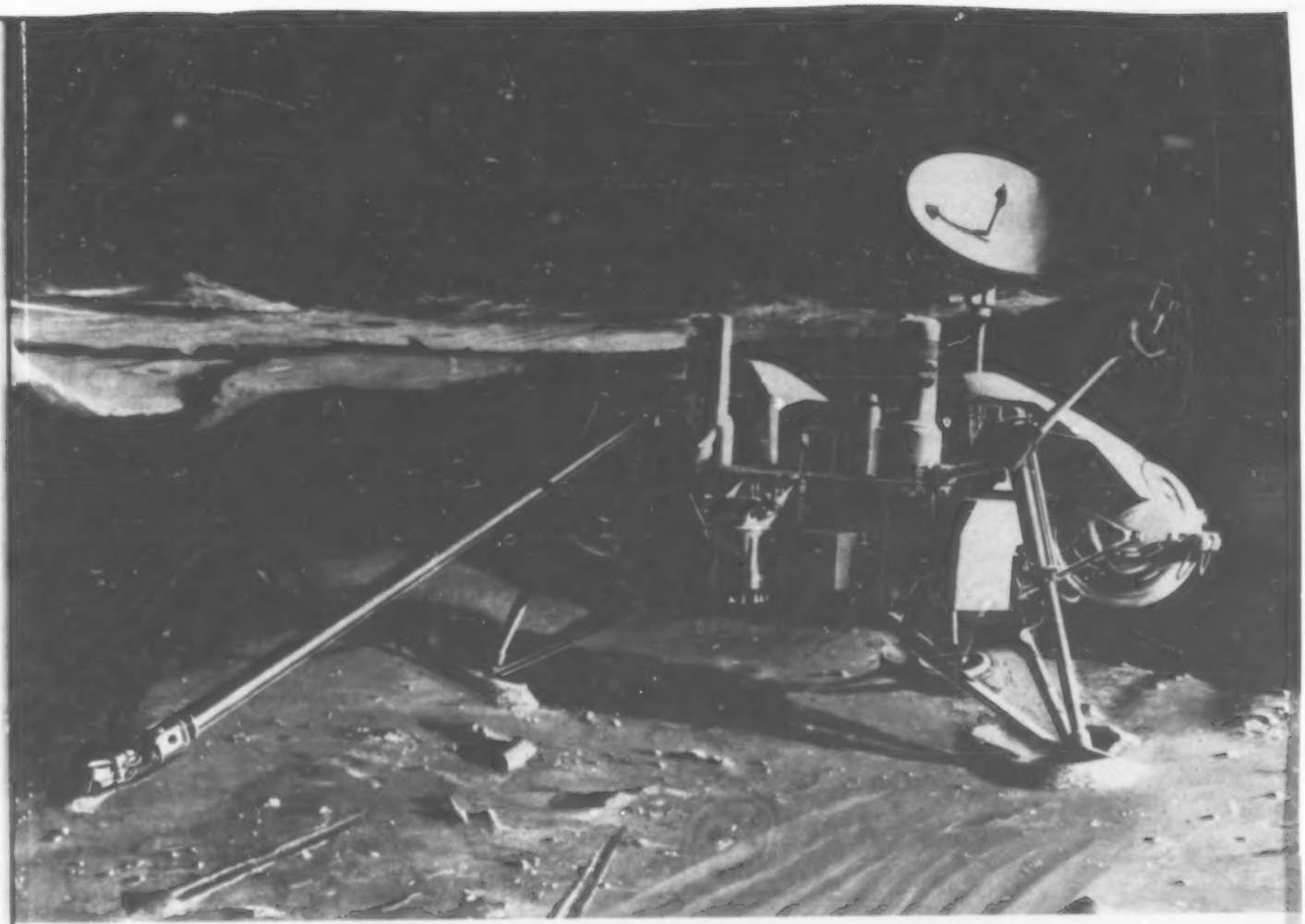


Figure 1. A **Stirling Engine** like the one shown here would be made with the new high-temperature-resistant alloys.



What's an Alloy Made in Kokomo, Indiana Doing on Mars?

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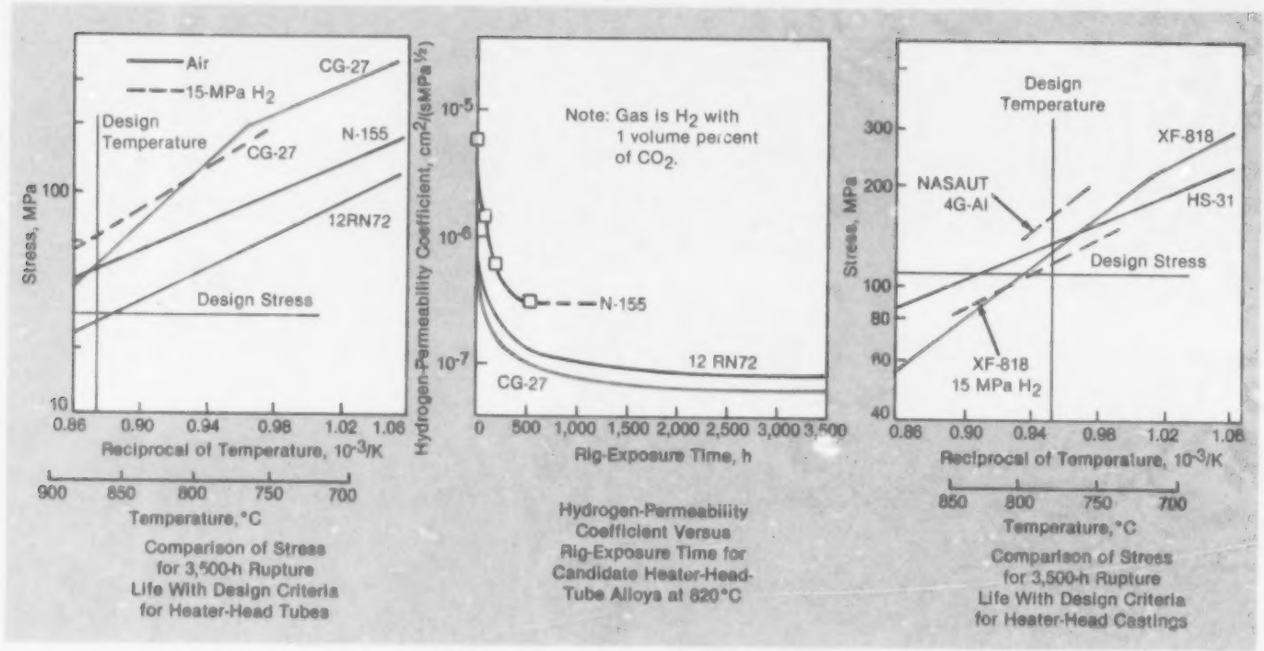

Figure 2. Some **Properties of Alloys** are compared to show the special utility of the new alloys.

and regenerator housing because of its good castability, strength (see Figure 2, bottom), ductility, and weldability. These advanced iron-base alloys have the potential for a variety of applications, including stationary solar-power systems.

This work was done by Joseph R. Stephens and Robert H. Titran of **Lewis Research Center**. *Further information may be found in NASA TM-83659 [N84-28963/NSP], DOE/NASA/51040-54, "Advanced High Temperature Materials for the Energy Efficient Automotive Stirling Engine."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
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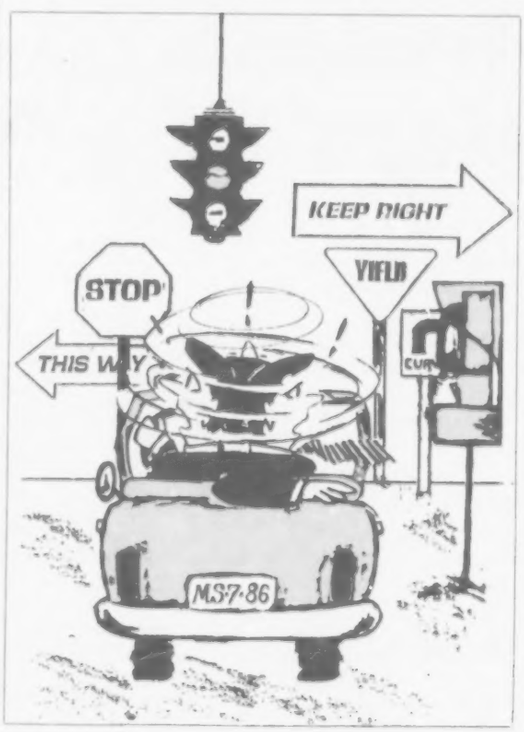

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Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Responses of Dielectrics to Space Radiation

The nature, extent, and possible prevention of radiation damage are discussed.

A report summarizes the likely effects of high-energy radiation in outer space on a variety of commercially-available dielectric materials used in spacecraft. The effects are reported on the basis of recent Galileo tests, unpublished tests involving proton or electron irradiation, and published information.

The types of particles and electromagnetic radiation encountered in space are complex and depend upon the particular mission trajectory. Radiation-induced changes result from ionization processes or atomic displacements, which can lead to both chemical reactions and changes in local microscopic structure. The size of a radiation-induced change can depend upon the total amount, intensity, composition, energy spectrum and impingement angle of the radiation, the composition of the immediate surroundings, the presence or absence of shielding, and the amounts of such other stresses as temperature, humidity, and electric fields.

In general, organic materials with carbon or inorganic fillers are most resistant to radiation. Moreover, the response of a given material to radiation can be modified by surface contamination or erosion by atomic oxygen, especially in orbits near the Earth.

Materials used in the Galileo orbiter (designed for the exploration of Jupiter, Saturn, and beyond) were selected for proton/electron irradiation tests. Some samples showed small amounts of surface cracking in the proton tests. In the electron tests, some adhesives lost strength, and some dielectrics changed in color. The major result was that zinc orthotitanate (used as a thermal-control coating) underwent a significant change when exposed to the maximum Galileo mission proton-radiation test level of 2.8×10^{10} rad. Although its emissivity increased by only 9.22 percent, its white absorptance increased from 0.13 to 0.42, or 249 percent.

The radiation-induced conductivity of a variety of dielectrics was investigated. Conductivity phenomena are numerous and complicated, involving many poorly-understood chemical and physical damage mechanisms, both in the bulk material and on the surface.

Charge buildup is related to conductivity. Experimental data on charge buildup and release are nearly in agreement with the predictions of a model based on the trapping of electrons in insulators. The response of the charge buildup and release depends on the ratio of the material relaxation time constant to a release rate from traps.

Certain organic additives increase the radiation resistances of polymers. Any additive material that would absorb or otherwise eliminate free radicals might reduce the vulnerability to radiation by blocking the damaging action of excited radicals. Conductive polymers should be useful in the prevention of charge buildup that could lead to deleterious results.

This work was done by Frank L. Bouquet of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Response of Dielectrics to Space Radiation," Circle 3 on the TSP Request Card.*
NPO-16687

Thermal Conductances of Pressed Copper Contacts

Measurements at liquid-helium temperatures are reported.

A report describes an investigation of the thermal conductivities of smooth copper contacts pressed together at liquid-helium temperatures. The investigation was prompted by the need for accurate thermal models for infrared detectors and other cryogenic instruments.

Previous studies of pressed contacts had shown that they do not obey the Wiedemann-Franz law, according to which the ratio of thermal to electrical conductivity is proportional to the absolute temperature. In addition, the thermal conductances of contacts are difficult to predict because even the smoothest surfaces have irregularities that limit the touching area to as few as three small spots, regardless of sample size. In fact, experiments have shown that the contact conductance depends on the force of contact rather than on the nominal contact area.

As the contact force increases, the material deforms. Thus, the touching area increases, and new spots develop. Heat flow is constricted in the vicinity of the touching locations by the narrowness of the touching spots. This constriction is responsible, in large part, for the contact thermal resistance.

For lack of an adequate theory to predict the contact thermal conductance as a function of the temperature and contact force, measurements were taken on pairs of lapped, flat samples of oxygen-free, high-conductivity copper. Each sample pair was tested at temperatures from 1.6 to 4.2 K while squeezed together with forces ranging from 0 to 670 N. With both samples cooled by liquid helium, one was heated slightly by an electrical-resistance heater, and the heat flow and temperatures were measured in the two samples.

The experimental data were fitted to the equation

$$\dot{Q} = \alpha \left(\frac{T_u^{n+1} - T_l^{n+1}}{n+1} \right)$$

where $\dot{Q}$ = the rate of heat flow across the contact, and T_u and T_l represent the upper- and lower-sample temperatures, respectively. The experimental results are presented in tables and a graph. For fixed values of the contact force, n ranges from 1.9 to 2.2, suggesting that the contact conductance varies approximately as the square of the absolute temperature.

The report does not present a quantitative evaluation of the increase in the contact conductance with the contact force. However, it appears from a cursory examination of the graph that, at a fixed temperature, the conductance is roughly proportional to the force to the 2/5 power.

This work was done by L. J. Salerno and P. Kittel of **Ames Research Center** *and A. L. Spivak of Trans Bay Electronics. For further information, Circle 37 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11572.

Computer Programs

90 **Analyzing Millimeter-Wave Mixers**
92 **Interface Program for Reliability Predictions**

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For additional information on any programs described in this issue of *Tech Briefs*, circle the appropriate number on the TSP card at the back of the publication. If you don't find a program in this issue that meets your needs, you can call COSMIC directly at (404) 542-3265 and request a review of programs in your area of interest. There is no charge for this information review.

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Computer Programs

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Electronic Components & Circuits

Analyzing Millimeter-Wave Mixers

An indepth analysis of the electrical characteristics will pave the way to improved mixers.

A series of computer programs have been developed to serve as a tool in understanding the behavior and the subsequent optimization of millimeter-wave mixers. The major program in the collection is a general mixer-analysis program that performs a complete large- and small-signal analysis of a mixer with known diode and mount characteristics. One program analyzes the performance of varactor-diode multipliers, and two programs analyze channel-waveguide transformers.

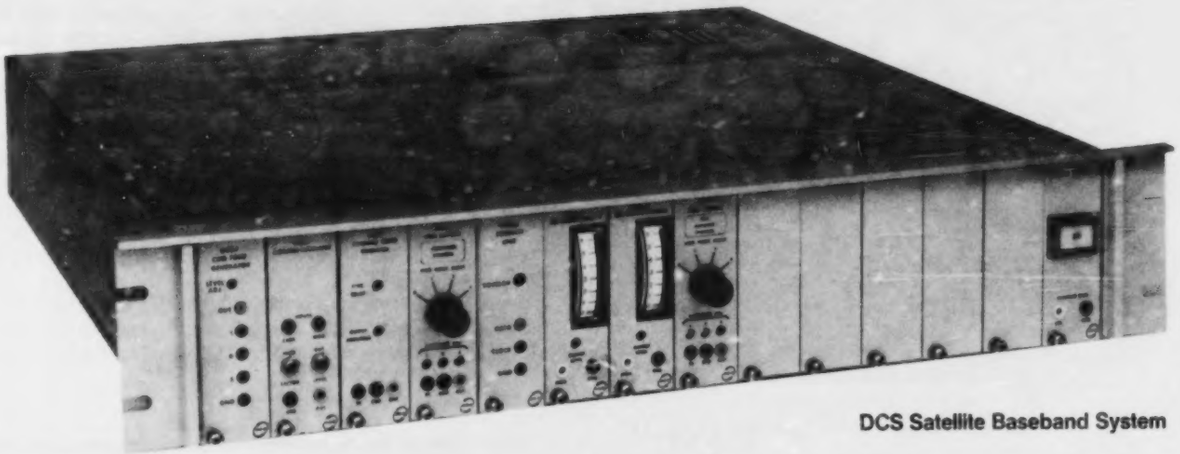
The primary objective behind developing these programs was to gain a better understanding of the factors that affect the performance of room-temperature, single-ended Schottky-diode mixers operating above 100 GHz. However, these programs are general enough to be applied to a wide variety of mixer problems.

In the mixer-analysis program, the large-signal voltage and current waveforms produced in the diode by the local oscillator (LO) and the available mixer LO power are determined by a nonlinear circuit analysis based on the multiple-reflection technique. This approach can handle a diode with any given current-versus-voltage and capacitance-versus-voltage relationships.

The Fourier coefficients of the large-signal waveforms are used in a small-signal analysis to obtain the mixer input and intermediate-frequency (IF) output impedances and the conversion losses between any two side-band frequencies. Both the thermal noise produced in the diode series resistance and the shot noise from the periodically pumped current in the diode conductance are determined. The effects of intervalley scattering and hot-electron noise can be included as approximations.

The multiplier-analysis program is a variation of the mixer-analysis program. The analysis is performed for a particular input frequency, available output power, bias voltage, and a given set of embedding impedances.

Two programs are provided to analyze a stepped or tapered transformer of the



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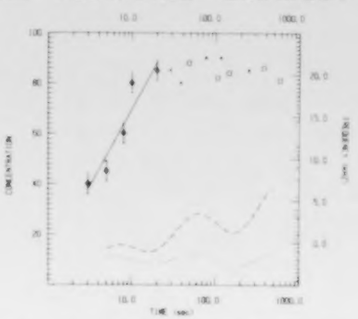

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type often used to minimize the mismatch between the mixer or multiplier and an impedance-matching, reduced-height waveguide. The first program finds the cutoff wavenumbers along the length of the transition from the method of transverse resonance, and then uses the characteristic-impedance method to calculate the reflection coefficient as a function of frequency. The second program solves the wave equation to find the cutoff wave numbers, then uses the characteristic-impedance method.

This series of programs is written in FORTRAN IVH for batch execution and has been implemented on an IBM 370-series computer. The largest program has a central-memory requirement of approximately 74K of 8-bit bytes. The programs were developed in 1983.

These programs were written by P.H. Siegel and A.R. Kerr of **Goddard Space Flight Center** *and W. Hwang of Columbia University. For further information, Circle 43 on the TSP Request Card.*
GSC-12940

Electronic Systems

Interface Program for Reliability Predictions

The user is assisted by numerous menus and prompts.

CARE3MENU generates an input file for the CARE III program. CARE III is used to predict the reliabilities of complex, redundant, fault-tolerant systems, including digital computers, aircraft, and nuclear and chemical control systems. The CARE III input file often becomes complicated and is not easily formatted with a text editor. CARE3MENU provides an easy interactive method of creating an input file by automatically formatting a set of user-supplied inputs for the CARE III system. CARE3MENU provides detailed online help for most of its screen formats.

The reliability-model input process is divided into sections, using menu-driven screen displays. Each stage, or set of identical modules comprising the model, must be identified and described in terms of the number of modules, the minimum number of modules for stage operation, and the critical fault threshold. The fault-handling and fault-occurrence models are detailed in several screens by such parameters as transition rates, propagation and detection densities, Weibull or exponential characteristics, and model accuracy.

The system fault-tree and critical pairs fault-tree screens are used to define the governing system-failure logic resulting from component failures and to specify pairs of nearly coincident component failures that will cause system failure when they exist. Additional CARE3MENU screens prompt the user for output options and run-time control values, such as mission time and truncation values. There are 14 major screens, many with default values and HELP options.

The documentation includes the following: (a) a user's guide with several examples of CARE III models, the dialog required to insert them into CARE3MENU, and the output files created and (b) a maintenance manual for assistance in changing the HELP files and modifying any of the menu formats or contents.

CARE3MENU is written in FORTRAN II for interactive execution and has been implemented on a DEC VAX-series computer operating under VMS. This program was developed in 1985.

This program was written by Salvatore J. Bavuso of **Langley Research Center** *and John L. Pierce of Research Triangle Institute, Paul L. Petersen of Kentron International, Inc., and Alan Roberts of Tesserract Systems. For further information Circle 134 on the TSP Request Card.*
LAR-13514

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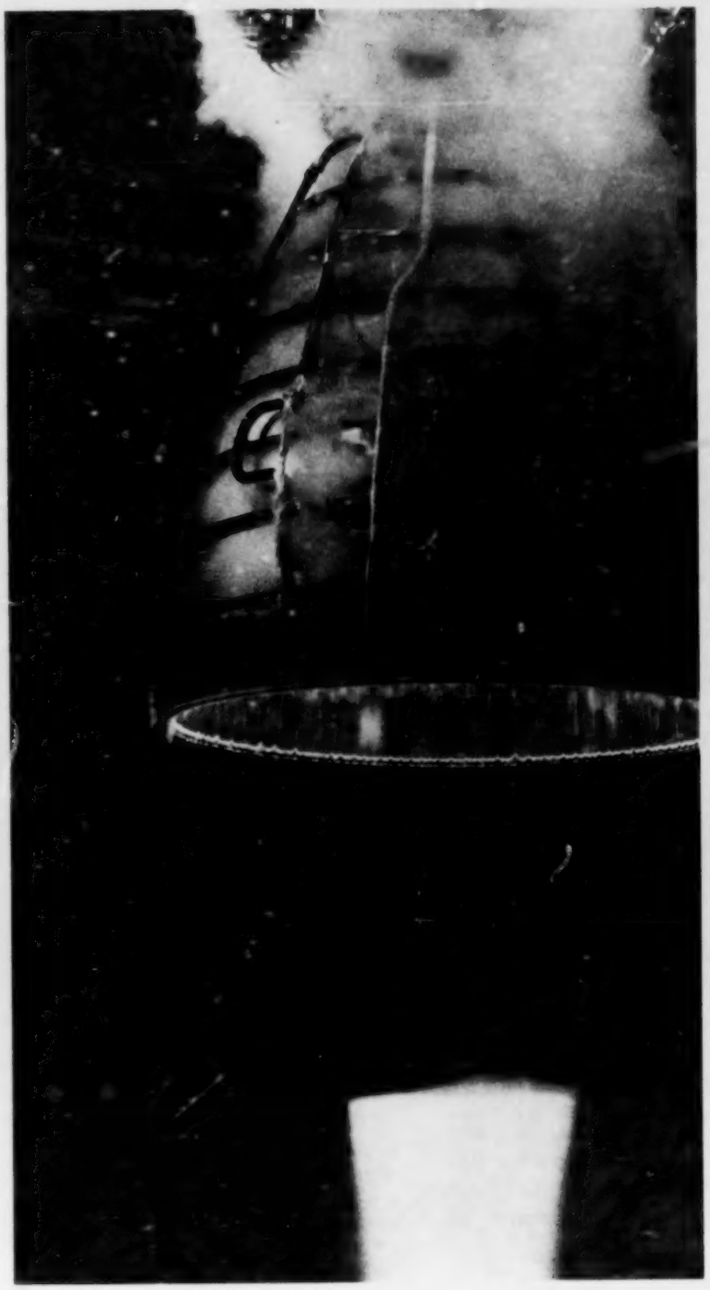

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Mechanics

Hardware, Techniques, and Processes

94 **Acoustic Coupler for Monitoring Bearing Wear**
96 **Testing Gimbal Axes Before Complete Assembly**
98 **Perturbation Method for Computational Fluid-Dynamic Equations**
103 **Capacitive Gauge Measures Film Thickness**
104 **Studying Transonic Gases With a Hydraulic Analog**
105 **Sealing a Loosely Fitting Valve Assembly**

Acoustic Coupler for Monitoring Bearing Wear

Coupler ensures efficient transfer of sound energy while protecting a piezoelectric sensor.

Marshall Space Flight Center, Alabama

A concept for an acoustic coupler would allow sound to be efficiently conveyed from bearings to an external sensor. Noise from bearings in a bearing test machine can be monitored for signs of incipient failure.

The proposed coupler (see figure) would extend in a straight line from a bearing. The feedthrough and seal allow a constant axial load to be applied to the coupling rod.

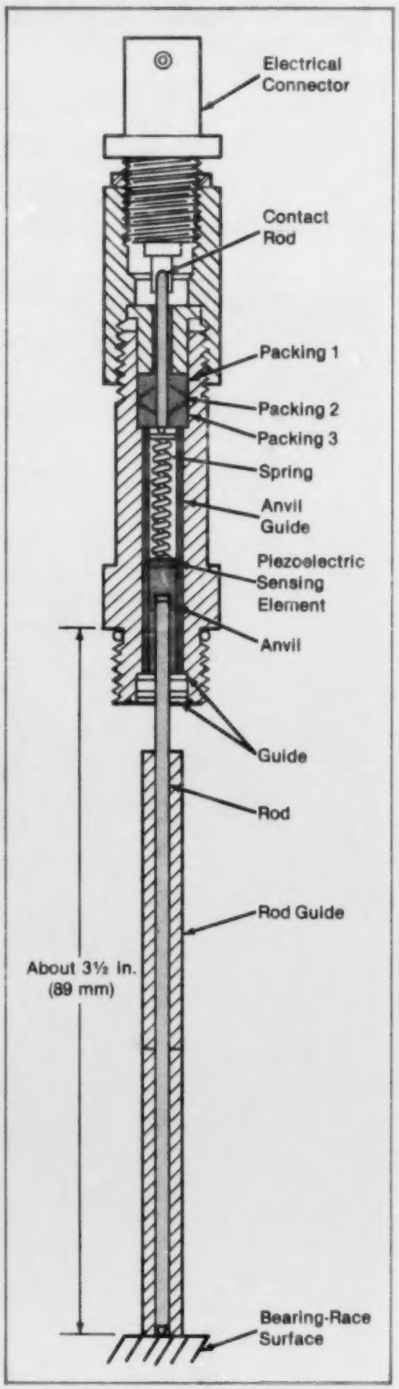
The electrical connection to the coaxial cable connector at the top of the assembly is made through a solid rod that passes through the packing gland. An adjustable force is applied through a compression spring to the piezoelectric element and the anvil between the element and the coupling rod. The force also holds the rod in contact with the bearing-race surface, maintaining constant contact pressure over a wide range of temperatures.

The anvil guide — a polytetrafluoroethylene tube — provides electrical insulation and acoustic isolation for the piezoelectric element. The rod guide provides further acoustic isolation, since it prevents direct contact between the coupling rod and the narrow channel between the feedthrough and the bearing-race surface.

The coupling rod passes through instrumentation ports in the bearing housing but not through coolant channels. It is therefore isolated from the turbulence in the flowing coolant that surrounds the bearing. The turbulence otherwise would vibrate, bend, or break the coupler.

The coupler is designed to pass sound frequencies between 100 kilohertz and 1 megahertz. This passband minimizes the lower frequency turbulence noise that reaches the piezoelectric element while transmitting the higher-frequency, bearing-damage noise.

This work was done by W. D. Jolly of Southwest Research Institute for **Marshall Space Flight Center**. *For further information, Circle 4 on the TSP Request Card.*
MFS-27077



The **Straight-Through Acoustic-Coupler Assembly** can be inserted through existing ports in the housing of a bearing-testing machine. The threaded electrical connector at the top can be rotated to adjust the force applied to the sensing element and the contact bearing.

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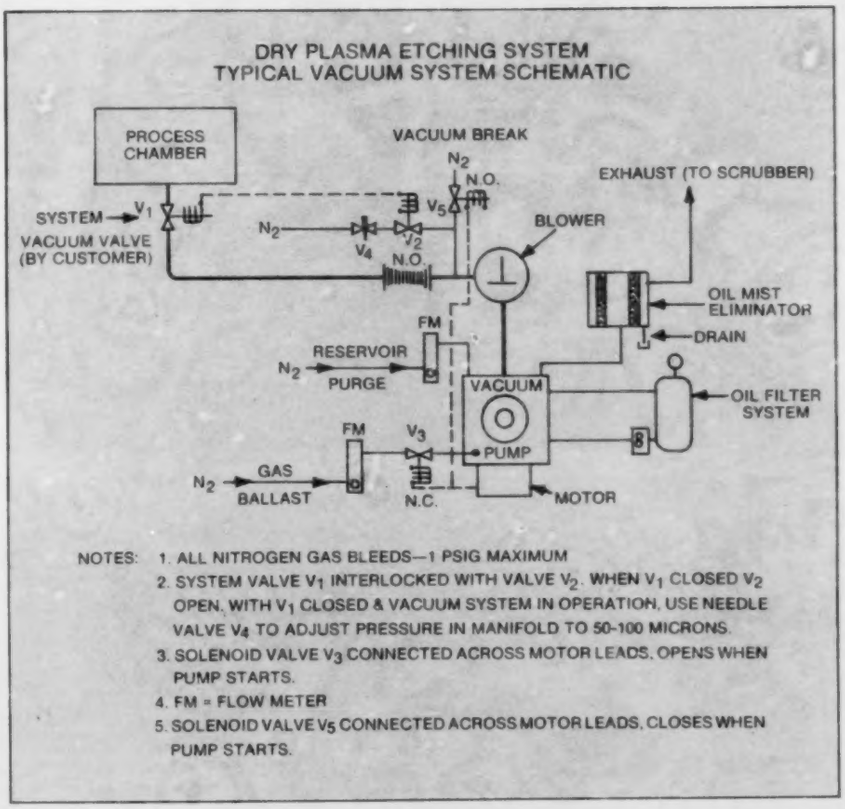
VAC-TECH NEWS

How to stop water vapor from destroying your vacuum system when you're plasma etching.



Due to the corrosive nature of the gases used and the particulates generated, plasma etching can impose harsh requirements on your vacuum system.

The presence of water vapor makes these conditions even more severe.

To keep your vacuum system performing to its capabilities, you must prevent water vapor from entering the system. If it does, you must remove it quickly.

The following installation and operation procedures will help you keep your system operating smoothly.

The right installation.

Install PVC exhaust piping instead of galvanized or black iron pipe, and an oil mist eliminator to reduce oil loss from the pump.

The exhaust line should be installed so it can easily be disassembled for periodic cleaning and the vacuum manifold must be leak-free.

The right operation.

Operate the vacuum system continuously and make sure the vacuum pump is gas ballasted during processing with a nitrogen flow rate of 1 to 2 L/M.

Purge the reservoir with nitrogen (in humid ambients it may be necessary to increase the nitrogen flow). Do not pump on the process chamber with the vacuum system at blank-off pressure as oil backstreaming may result. When necessary to shut down the vacuum system for over 8 hours, fill gas ballast with nitrogen for at least 4 hours before stopping.

The right maintenance.

Drain the exhaust oil mist eliminator weekly. If oil is clean, it can be reused by returning to the pump. If it is "milky" or cloudy, it should be decanted before returning to pump reservoir. Cleaning interval is determined by the amounts of particulates accumulated.

Monitor differential pressure across the oil filter. Replace element when filter pressure shows a significant increase above baseline pressure. Actual pressures will be determined by your own process.

Open pump reservoir at 2-month intervals to remove sediment from bottom of the reservoir. And when the particulate oil filter elements are used, replace element when filter pressure as shown on the gage is exceeded.

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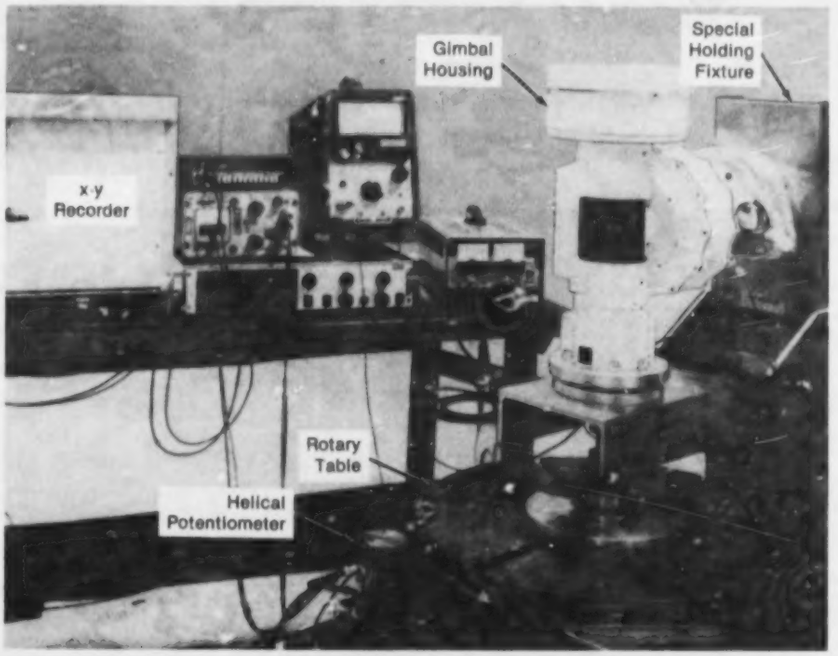
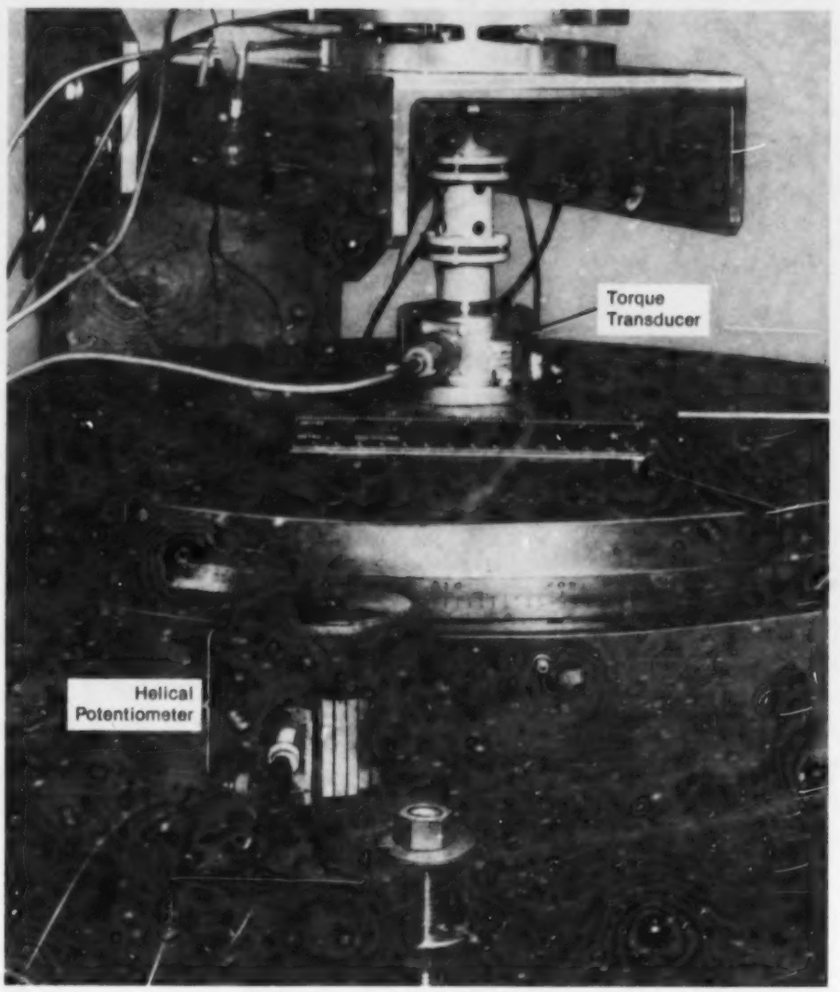
Testing Gimbal Axes Before Complete Assembl





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plete Assembly

Early testing increases chances that the assembly will function well without expensive rework.

Lyndon B. Johnson Space Center, Houston, Texas

A preassembly test ensures that a gimbal axis functions properly before further time and work are invested in assembling the entire gimbal. Developed for antenna gimbals, the test eliminates the delay and costs that ensue when a fully assembled antenna fails because of excessive torque and friction in the gimbal. The time required to disassemble, repair, reassemble, and retest a defective unit is about 7 working days. With the new test, gimbal motors can be installed and the test can be performed in about 1 day. If performance is unsatisfactory, corrections can be made before any further assembly is done.

A special fixture was developed to hold the gimbal housing with the axis to be tested coinciding with the axis of a rotary table (see Figure 1). A torque transducer is mounted on the rotary table. A flexible torque coupling connects the gimbal-axis shaft with the torque transducer. Standard instrumentation furnishes power and monitors and records the test.

A constant direct current is supplied to the axis motor. The rotary table is turned from one stop of the gimbal to the other and back to the original position. Meanwhile, the output of the torque transducer is recorded on the vertical (y) axis of an x-y recorder (see Figure 2). The shaft of a helical potentiometer is coupled to the rotary table, and the potentiometer output is fed to the horizontal (x) input of the x-y recorder to indicate the rotary-table position. The dc voltage supplied to the potentiometer can be increased to expand the horizontal scale.

Plots are made for two directions of motor current. Suspect portions of a plot can be examined further by repeating the test with the horizontal scale expanded in the area of interest.

Any corrections needed in the gimbal are made, and the test is repeated. After the test is completed successfully, assembly can proceed with high confidence that the final unit will meet its requirements.

This work was done by W. Babis of Hughes Aircraft Co. for **Johnson Space Center**. *No further documentation is available. MSC-20809*

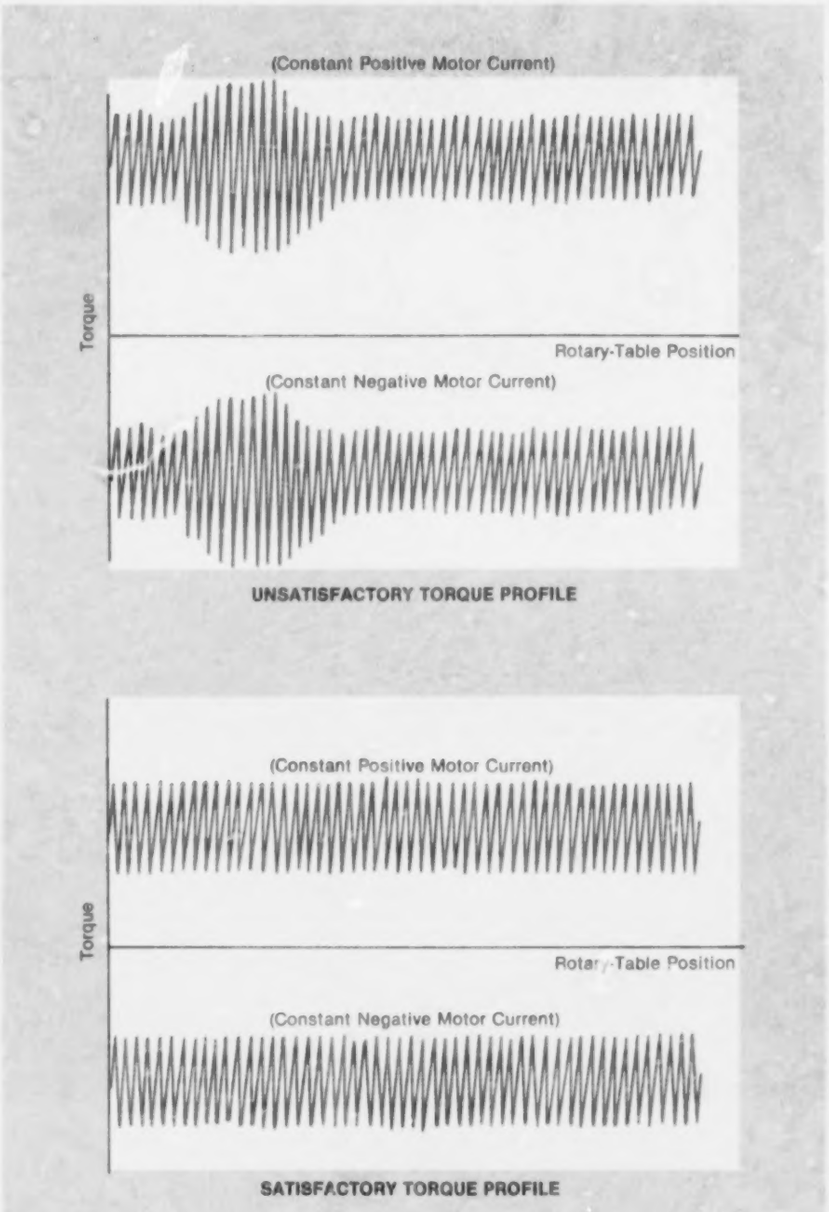


Figure 2. **Unacceptably High Bearing Friction** is reflected in the bulge in the upper plot of the torque on the alpha axis of a gimbal for a K_u-band antenna. The bulge appears for both positive and negative directions of motor current.

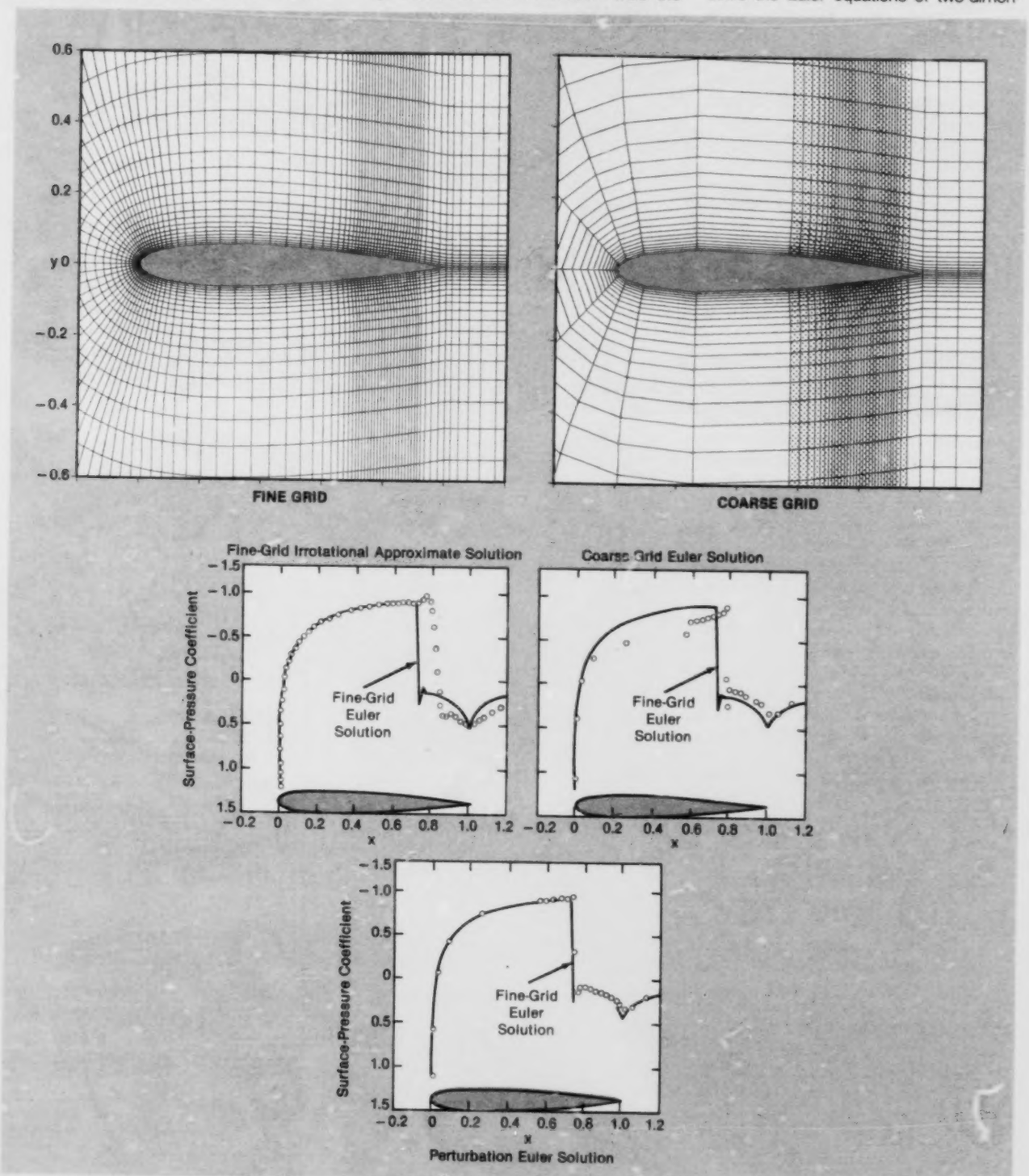
◄ Figure 1. The **Gimbal Housing Is Mounted** above a rotary table. The gimbal axis to be tested is connected to a torque transducer on the table. With the exception of the special holder for the gimbal housing, all of the testing instruments are commercially available items.

Perturbation Method for Computational Fluid-Dynamical Equations

This technique reduces the grid-point density required for accurate results.

Ames Research Center, Moffett Field, California

A perturbation technique yields accurate flow solutions using as few as one-fourth the number of grid points required by finite-difference methods. While the technique was originally developed to solve the Euler equations of two-dimen-



A Coarse-Grid Perturbation Euler Solution for a transonic, nonlifting airfoil operating at a free-stream mach number M_∞ of 0.85 and an attack angle α of 0° are compared here with both fine- and coarse-grid Euler solutions.

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sional, steady, inviscid transonic flow about airfoils, it is applicable to arbitrary equation sets and higher dimensions.

A smooth, gradually varying function can be resolved accurately with fewer grid points than can a rapidly varying one. To exploit this fact, the governing equations are rewritten in terms of a perturbation about a known nearby or approximate base solution. The base solution should be easily obtainable and must be a good approximation over most of the flow domain. In most of the flow domain, the perturbation quantity (the difference between the two solutions) will then be a smooth, gradually varying function, and the computation grid can be coarsened without appreciable loss of accuracy.

The figure shows the results of one of a series of calculations of transonic, rotational flow about an airfoil. As is typical in the flow-speed range studied, the irrotational approximate solution overpredicts the shock strength and places the shock about 10 percent of chord further downstream.

The 91-by-33-point coarse grid is a subset of the fine grid. It was obtained by discarding grid points in the nose and wake regions. The coarse-grid conventional Euler solution computed with the standard Euler algorithm agrees poorly with the fine-grid Euler solution. (The coarseness of the grid and the discontinuous spacing degrade the solution considerably.) However, the perturbation Euler solution computed on the same coarse grid agrees well with the fine-grid Euler solution. In this and all the other cases studied, the perturbation Euler solutions accurately capture steady, two-dimensional transonic solutions on very coarse grids.

For the airfoil cases studied, the computation time required for the coarse-grid Euler perturbation calculations is only about one-quarter to one-half that for fine-grid Euler calculations of comparable accuracy. (In three-dimensional applications, the grid coarsening would reduce computation time even more dramatically.) The perturbation scheme requires 26 to 70 percent less array storage. Moreover, traditional means of accelerating iterative convergence can still be used, and the required perturbation source terms appear to be readily embeddable into any existing finite-difference code.

The new perturbation scheme could be used in a design cycle where potential solutions are generated routinely; the Euler perturbation method could be used in a second-cut analysis. The method could also be used to couple other equation sets. For instance, the Navier-Stokes (viscous-flow) equations could be perturbed about a full-potential/boundary-layer solution. Further investigation is warranted for other applications.

This work was done by Leslie J. Chow and Thomas H. Pulliam of **Ames Research Center** *and Joseph L. Steger of Stanford University. For further information, Circle 72 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11550.

Capacitive Gauge Measures Film Thickness

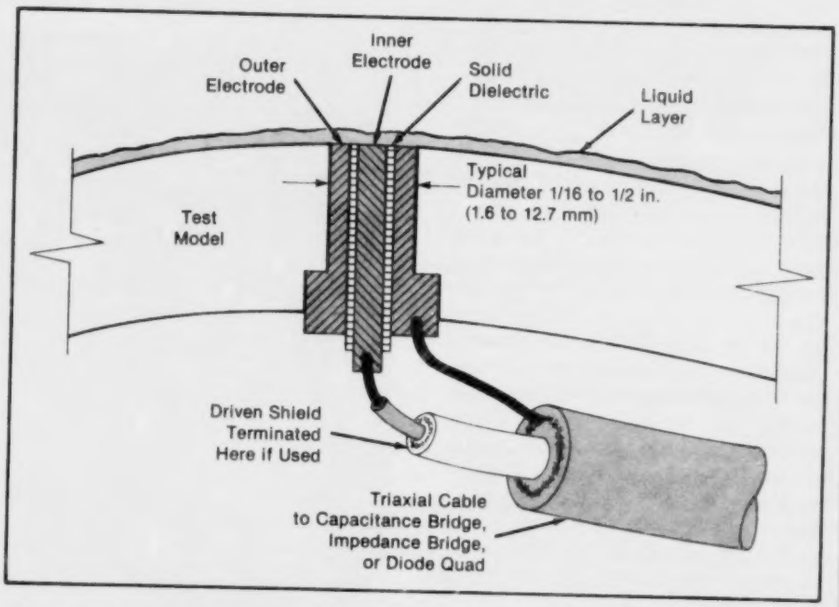
Continuous readings are obtained with minimal disturbance to flow.

Ames Research Center, Moffett Field, California

A rugged capacitive transducer measures the thickness of a film of liquid flowing over a wind-tunnel model or other object. The transducer is mounted flush with the surface of the model to preserve the model outline, thus minimally disturbing the wind-tunnel and film flows. Additional uses could include thickness control of paint or nonmetallic solid films.

The coaxial arrangement is easy to fabricate (see figure). The capacitance between the inner and outer electrodes increases with the dielectric constant and thickness of the liquid layer and is measured with a capacitance bridge or other suitable circuit.

A transducer of this type has been used to measure liquid film thicknesses in the submillimeter range. Other ranges could be measured with the proper choice of transducer dimensions and capacitance-bridge components. For each liquid of interest, the capacitance-bridge output can be calibrated directly in terms of the liquid depth: Depth measurements for calibration might be obtained, for example, with a depth micrometer equipped with a pointed stylus. The change of capacitance with depth will be approximately linear over a portion of the total depth range.


Inner Electrode
Outer Electrode
Solid Dielectric
Liquid Layer
Typical Diameter 1/16 to 1/2 in. (1.6 to 12.7 mm)
Test Model
Driven Shield Terminated Here if Used
Triaxial Cable to Capacitance Bridge, Impedance Bridge, or Diode Quad

The **Capacitance Between the Inner and Outer Electrodes** varies with the depth of liquid on the model surface. The liquid depth is inferred from the capacitance reading.

This work was done by H. Lee Seegmiller of **Ames Research Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11449.

Studying Transonic Gases With a Hydraulic Analog

A water table has been adapted to gas dynamics.

Marshall Space Flight Center, Alabama

A water table for hydraulic-flow research can yield valuable information about gas flow at transonic speeds. The water table has been used to study fuel and oxidizer flow in high-pressure rocket engines, in particular to study transonic flow at the walls of a combustion chamber. The chamber allowed new wall geometries to be evaluated quickly by visual observation.

The method can be applied to gas flows in such equipment as furnaces, nozzles, and chemical lasers. It is especially suitable when wall contours are nonuniform, discontinuous, or unusually shaped. Wall shapes can be changed quickly for study and evaluated on the spot. The method can be used instead of computer simulation when computer models are unavailable, inaccurate, or costly to run.

A full-scale, two-dimensional wall, representing one-half the flow chamber, is placed on the water table (see figure). A sheet of water flows over the table and around the wall. The depth of the sheet at any point is analogous to some of the characteristics of a gas at that point. For example, as the waterflow is accelerated to a speed analogous to that of a transonically flowing gas, the water depth falls to indicate lower pressure.

The water depths are measured at the center of the table and along the wall boundary to provide data for a grid of constant-speed contours. The water depth is proportional to the gas density, to the gas temperature, and to the square root of the gas pressure. Thus, plots of the density, temperature, and pressure can also be made. Researchers can see the flow pattern as ripples in the water surface.

In the rocket-engine problem, the radii of curvature of the combustion-chamber walls were reduced upstream and downstream of the throat as a result of the water-table experiments. The transonic-flow length was reduced, and the coolant pressure loss was decreased.

This work was done by W. R. Wagner and F. F. Lepore of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 8 on the TSP Request Card.*
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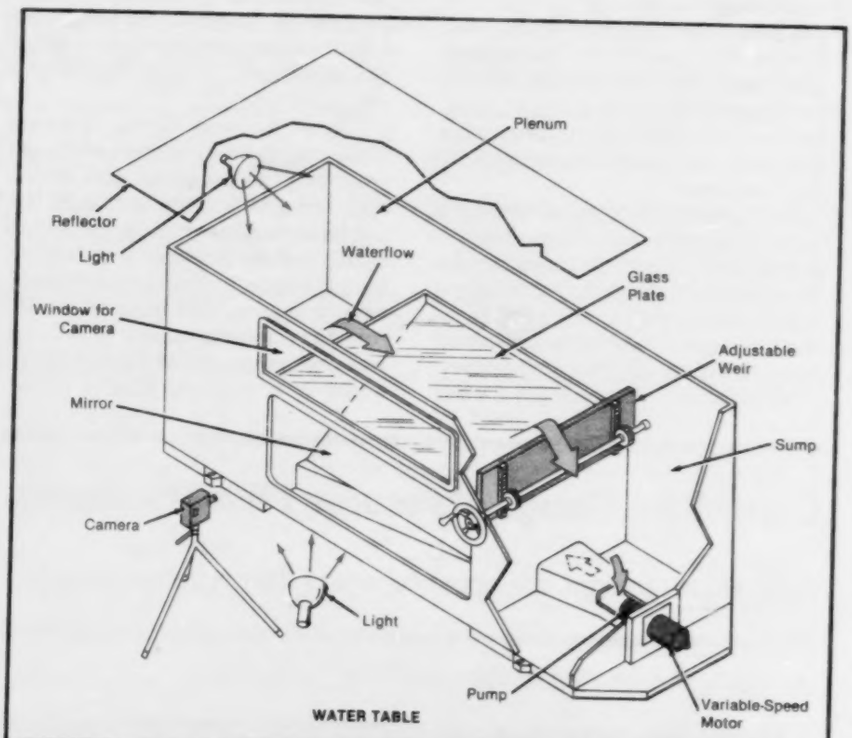
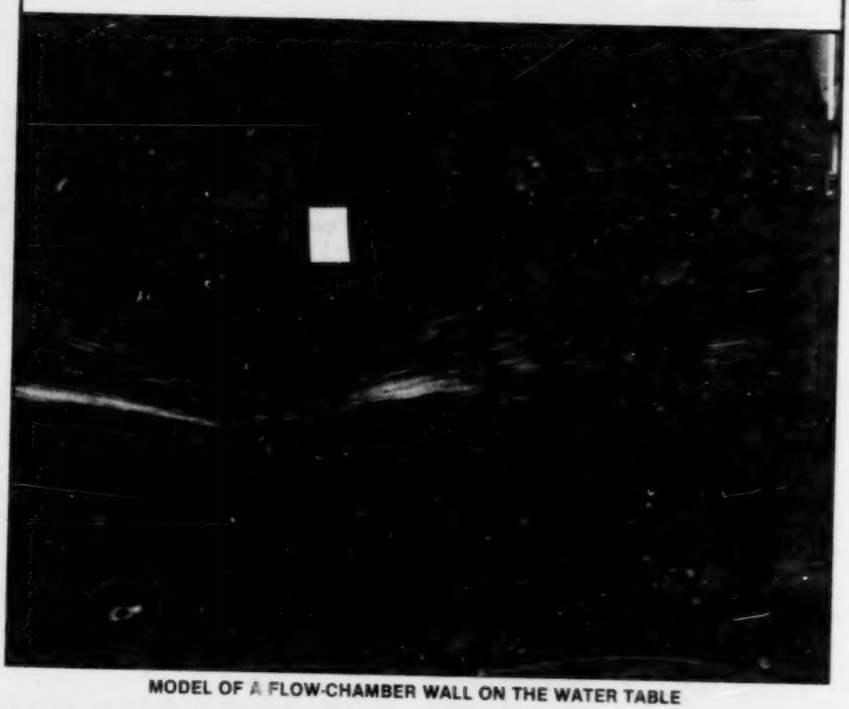


WATER TABLE



MODEL OF A FLOW-CHAMBER WALL ON THE WATER TABLE

Water Flows Over the Transparent Glass Plate of the water table. Flow patterns around objects on the table are clearly visible through windows, and the depth of the flowing water at various points can be readily measured.

Sealing a Loosely Fitting Valve Assembly

A double-ring seal avoids the expense of remachining or redesigning valve parts.

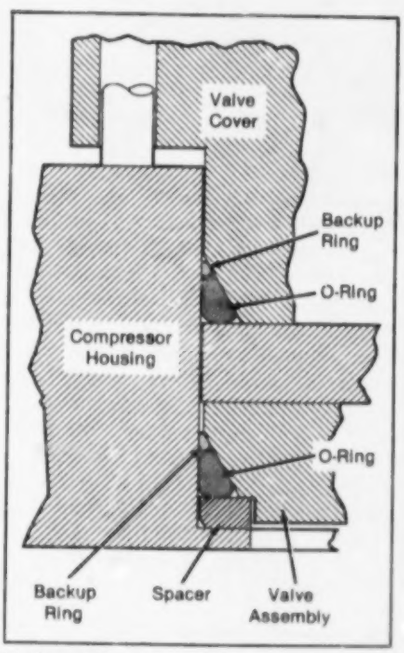
Marshall Space Flight Center, Alabama

An O-ring and a backup ring are combined to seal high-pressure hydrogen gas in a fitting that has loose clearances. The fittings are part of a valve on a hydrogen compressor.

Originally, bolt loading through a flange was used to create enough yield in metal sealing parts to form a leak-tight seal. With hydrogen and with the normal wear of the sealing surfaces, however, the bolt torque required for tight sealing became excessive and caused structural problems in the cast iron of the compressor housing.

The solution was to redesign the seal and use a totally captured O-ring and a glass-filled polytetrafluoroethylene backup ring. (The loose manufacturing tolerances of the valve components made it useless to machine a standard O-ring groove.) When the rings are installed in the valve, the O-ring forces the backup ring to conform to the gap between mating metal parts (see figure). At the same time, the backup ring prevents the O-ring from being extruded into the gap. The combination of rings thus ensures a tight seal and makes it unnecessary to remachine the parts or fabricate new ones to maintain tighter clearances. With the double-ring seal, the leakage of gaseous hydrogen is undetectable at a pressure of 850 lb/in.^{2} (5.9 MPa).

This work was done by L. R. Goff and G. F. Tellier of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-29051



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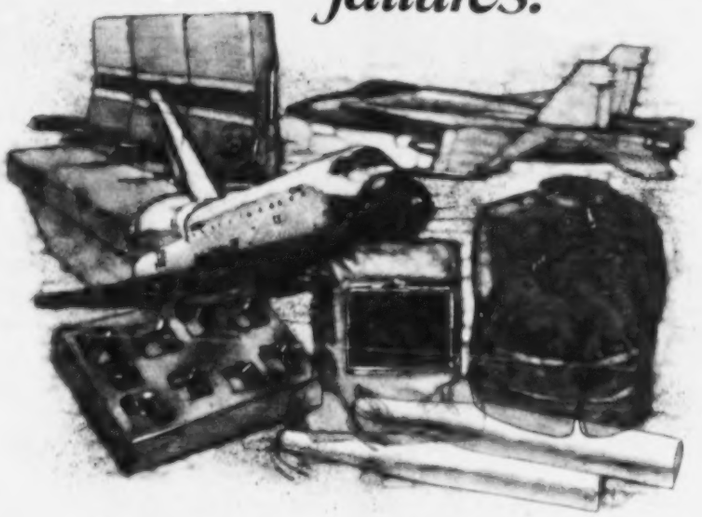

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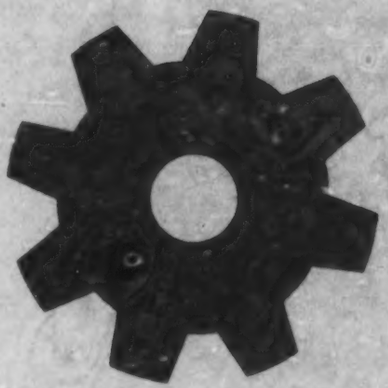

Hardware, Techniques, and Processes

106 Continuous Removal of Coal-Gasification Residue
109 Effects of Structural Flexibility on Aircraft-Engine Mounts
110 Shock-Absorbent Ball-Screw Mechanism
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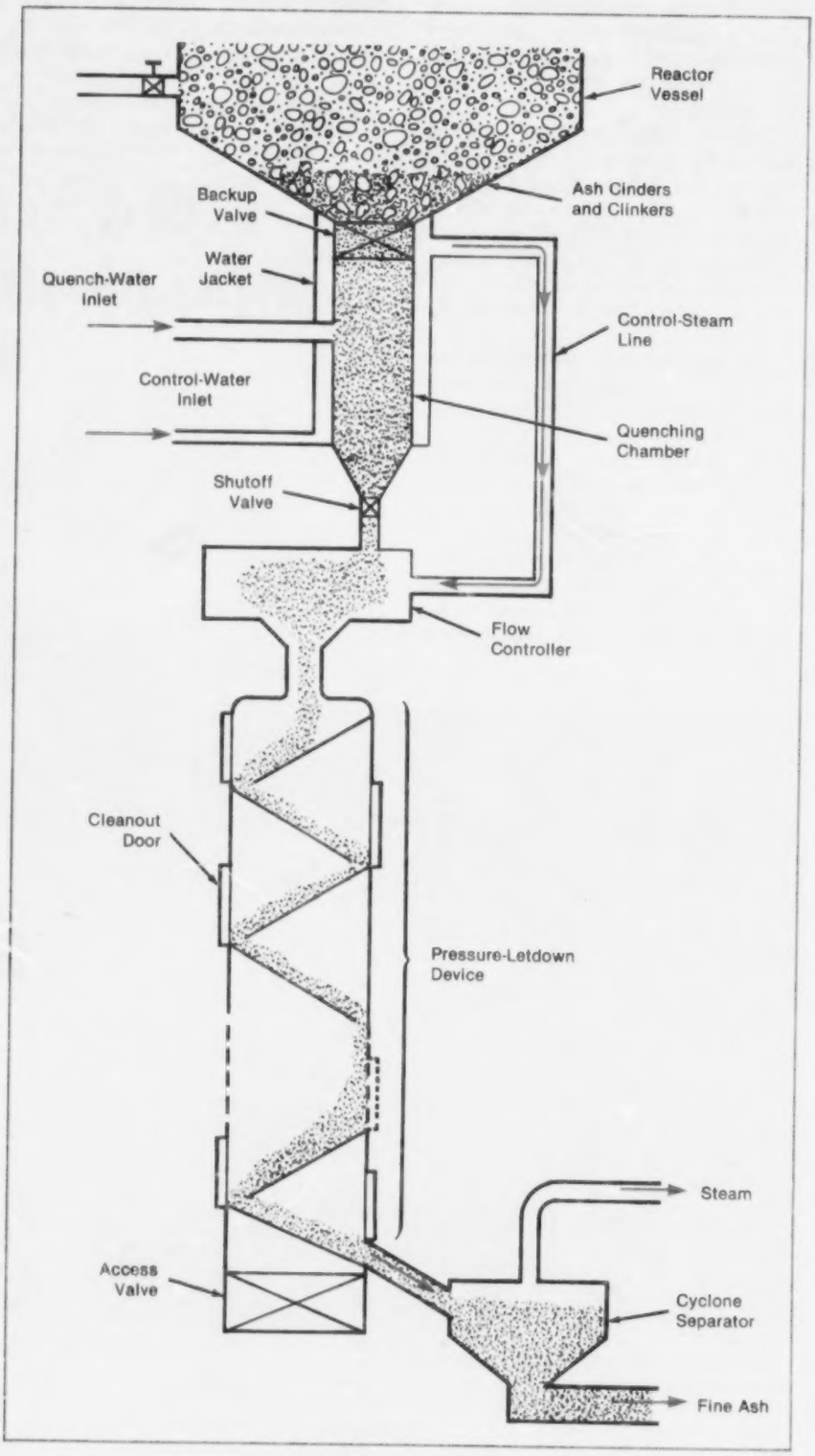
117 Heat Radiators for Electromagnetic Pumps
117 Long, Thin, Deployable Mast

Continuous Removal of Coal-Gasification Residue

Ashes would flow from a reactor in a continuous stream instead of in batches.



NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed continuous-flow hopper would process the solid residue from coal gasification, converting it from ashes, cinders, and clinkers to particles the size of sand granules. Unlike conventional ash lockhoppers, which operate on batches of materials, the proposed unit would not require repeated depressurization of the lockhopper to admit and release materials. It therefore would consume less energy. Because the unit has no airlock valves to be opened and closed repeatedly on hot, abrasive particles, it will be subjected to lesser wear.

According to the concept, as the hot ashes, cinders, and clinkers leave the reactor, a stream of quenching water hits them (see figure). The water flashes to steam on contact and explosively destroys the cinders and clinkers, reducing them to small particles. The ash and steam enter the flow controller where the flow is throttled to keep a high pressure in the reactor. A water jacket surrounding the quenching chamber absorbs enough heat from the ash to vaporize the water flowing through it. The resulting steam operates the flow controller.

The stream enters the pressure-letdown device, where the ashes move slowly from chamber to chamber, with minimal abrasion. In each chamber, the pressure drops slightly, reaching atmospheric pressure at the outlet. The openings between chambers are made progressively larger to accommodate the expanding volume of gas as the stream cools and depressurizes.

Finally, the stream feeds into a cyclone separator, which separates steam and coal gas, if any, from the ash. The steam can be used for heating. Alternatively, the steam can be used to drive a low-pressure turbine to generate electrical power. In this case, the steam would be separated before the ash is completely depressurized.

This work was done by Earl R. Collins, Jr., Jerry Suitor, and David Dubis of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 9 on the TSP Request Card.*
NPO-16605

◄ **Coal-Gasification Residue Flows** slowly through a pressure-letdown device. Material enters and leaves continuously. A cleanout door on each pressure-letdown chamber allows access for maintenance and emergencies.

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dp DESIGN PUBLICATIONS

Effects of Structural Flexibility on Aircraft-Engine Mounts

A design technique is used to decouple linear and rotational oscillations of the engine.

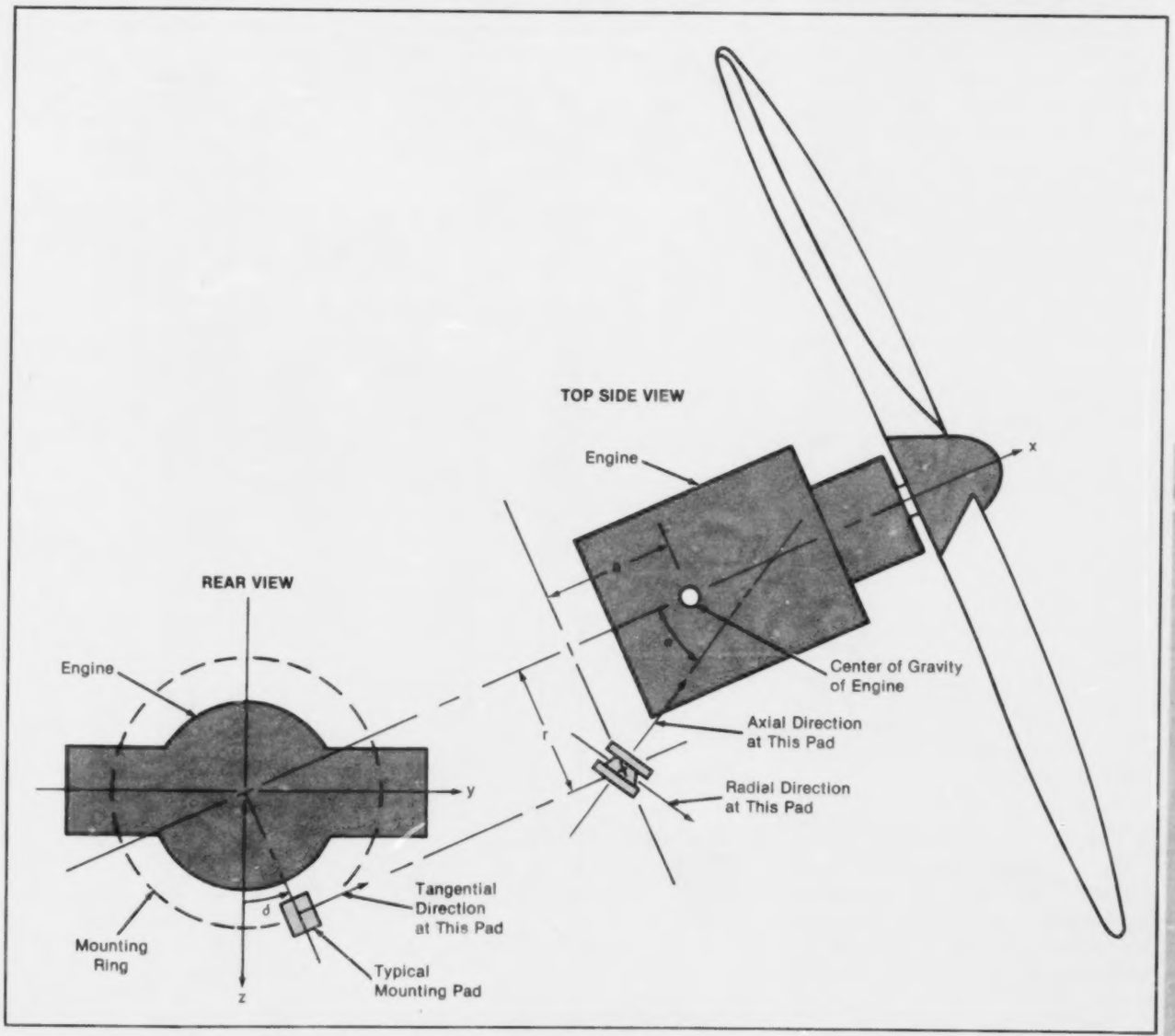
Langley Research Center, Hampton, Virginia

A new analysis extends a technique for the design of a widely used type of vibration-isolating mounts for aircraft engines, in which rubber mounting pads are located in a plane behind the center of gravity of the engine-propeller combination. Such mounts are frequently designed to decouple the linear and rotational motions of the engine. The present study extends the decoupling analysis to account for the flexibility of the mount structure.

The overall problem of vibration oscillation of an aircraft powerplant is a problem in dynamics, which can be exactly solved only by accounting for the distribution of mass and stiffness throughout the structure as well as for such factors as the gyroscopic effects of the engine and propeller. This new analysis, however, treats a problem in statics. The results of this simple approach are useful in providing equations for the design of the vibration-isolating mounts. The equations are believed to be applicable in the usual situation in which the engine-mount structure itself is relatively light and is placed between the large mass of the engine and other heavy components of the airplane.

In the engine-mount system illustrated in the figure, the engine is supported by m equally spaced mounting pads. The axis of each pad intersects the centerline of the engine at a common point and makes an angle α with the centerline. The vertical and pitching motions of the powerplant are considered. The same analysis is applicable to the lateral decoupling of engine vibrations (lateral movement and yawing rotation) by redefining axes.

From the relative displacements of the front and rear faces of each mounting pad, the axial, radial, and tangential forces produced on the engine by each pad are calculated. The forces are re-



This **Coordinate System** is used in analyzing the flexibility of the engine mounts.

solved along the powerplant axes, allowing the total vertical force and the moment about the center of gravity of the powerplant to be calculated. The stiffness components of the mount can be determined, and an equation can be obtained to express the decoupling in terms of α, the overhang ratio a/r, and the stiffness parameters of the system.

Equations and curves were developed to enable the design of mount systems and to illustrate the results for a range of design conditions. Arrangements of mounting pads other than those involving equal spacing around the mount ring may be analyzed by the equations developed. The results of this analysis show that the structural flexibility has a relatively small effect when the center of gravity of the engine is close to the plane of the mounting points, but it becomes more important as the distance between the center of gravity and the plane of the mounting points increases.

This work was done by William H. Phillips of **Langley Research Center.**

Further information may be found in NASA TM-85725 [N84-16590/NSP], "Effect of Structural Flexibility on the Design of Vibration-Isolating Mounts for Aircraft Engines."

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LAR-13305

Shock-Absorbent Ball-Screw Mechanism

End-of-travel impacts are safely absorbed, increasing the service life.

Ames Research Center, Moffett Field, California

An actuator containing two ball screws in series employs Belleville springs to reduce impact loads, thereby increasing its life expectancy. This new application of Belleville springs can increase the reliability of equipment in which ball screws are commonly used.

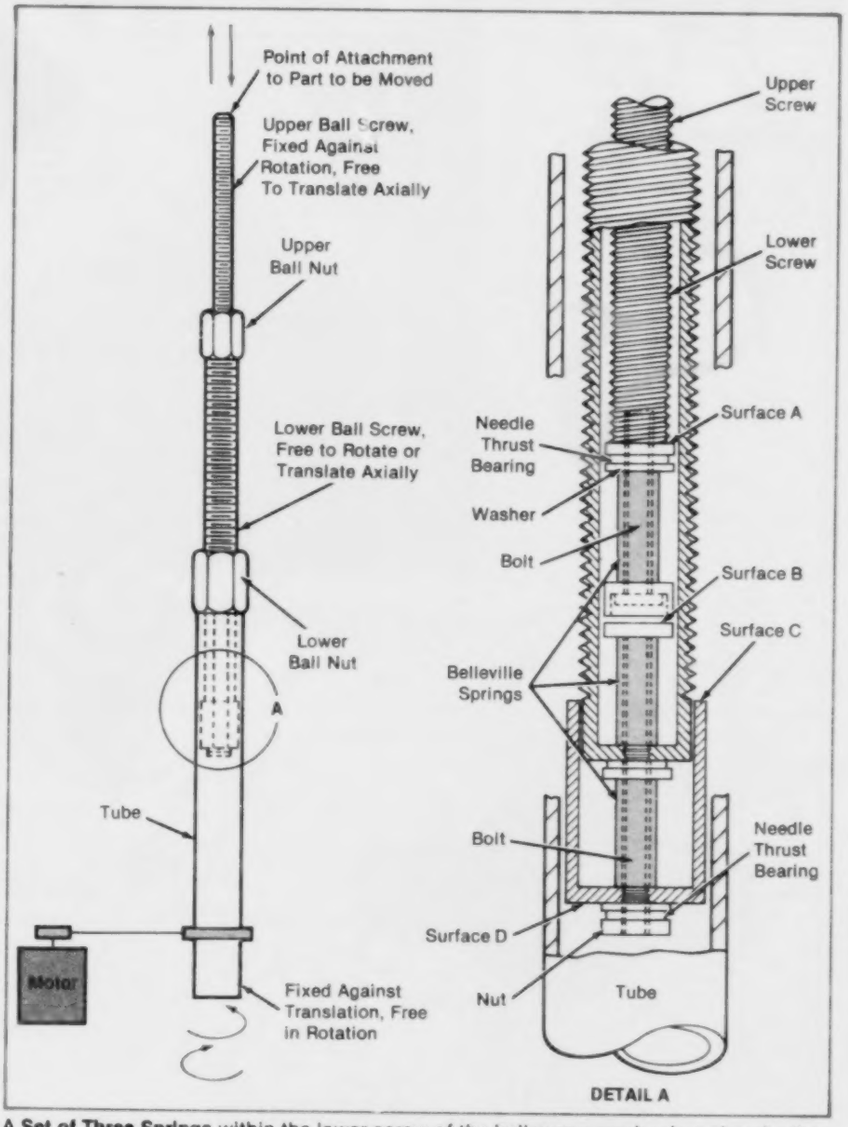
In addition to the two ball screws, the mechanism employs two ball nuts, a tube, and a drive motor (see figure). The two nuts are mounted at the tops of the lower screw and tube, respectively. The upper screw is held so that it may move only in axial translation. The lower screw is free to rotate or translate. The tube is held so that it may only rotate. When the tube is rotated, the lower screw rotates or translates, thereby translating the upper screw axially so that it raises or lowers a part attached to the upper tip of the mechanism.

Previously, a circular plate was attached to the lower end of each ball screw to strike the corresponding nut and thus limit the travel of the mechanism. The impact tended to wear out the mechanism rapidly.

In the new mechanism, the striking plates are replaced by three sets of Belleville springs. When the upper screw is in its lowest position, the uppermost spring is compressed against surface B. When the motor is started counterclockwise facing upward, it rotates the tube and the screws start to ascend.

As the upper screw reaches its limit of travel, surface A comes in contact with the upper ball nut. The upper spring is thus once again compressed, absorbing the kinetic energy released as the lower screw stops rotating and starts translating. When the lower screw reaches its upper limit, surface C makes contact with the lower nut, compressing the middle spring.

When the drive motor is reversed, the screws start to descend. The lower screw is stopped in its descent when surface D



A Set of Three Springs within the lower screw of the ball-screw mechanism absorbs the impacts that result when the parts reach their upper and lower limits of movement. The mechanism is shown near its lowest position.

strikes the bottom of the tube. When this happens, the lower spring absorbs the kinetic energy. The upper screw is stopped in its descent when contact is made at surface B.

The compression forces are applied to the springs through needle-thrust-bearing-and-washer assemblies. If the forces were applied directly, the screws would tend to lock because of friction between the spring ends and the contact surfaces.

The mechanism was designed with Belleville springs as the shock-absorbing elements because Belleville springs have a good energy-to-volume ratio and are easily stacked to attain any stiffness and travel.

This work was done by Otto A. Hirr, Jr., and Robert W. Meneely of **Ames Research Center**. *For further information, Circle 29 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11366.

Improved Orifice Plate for Spray Gun

Spray patterns are made repeatable.

Marshall Space Flight Center, Alabama

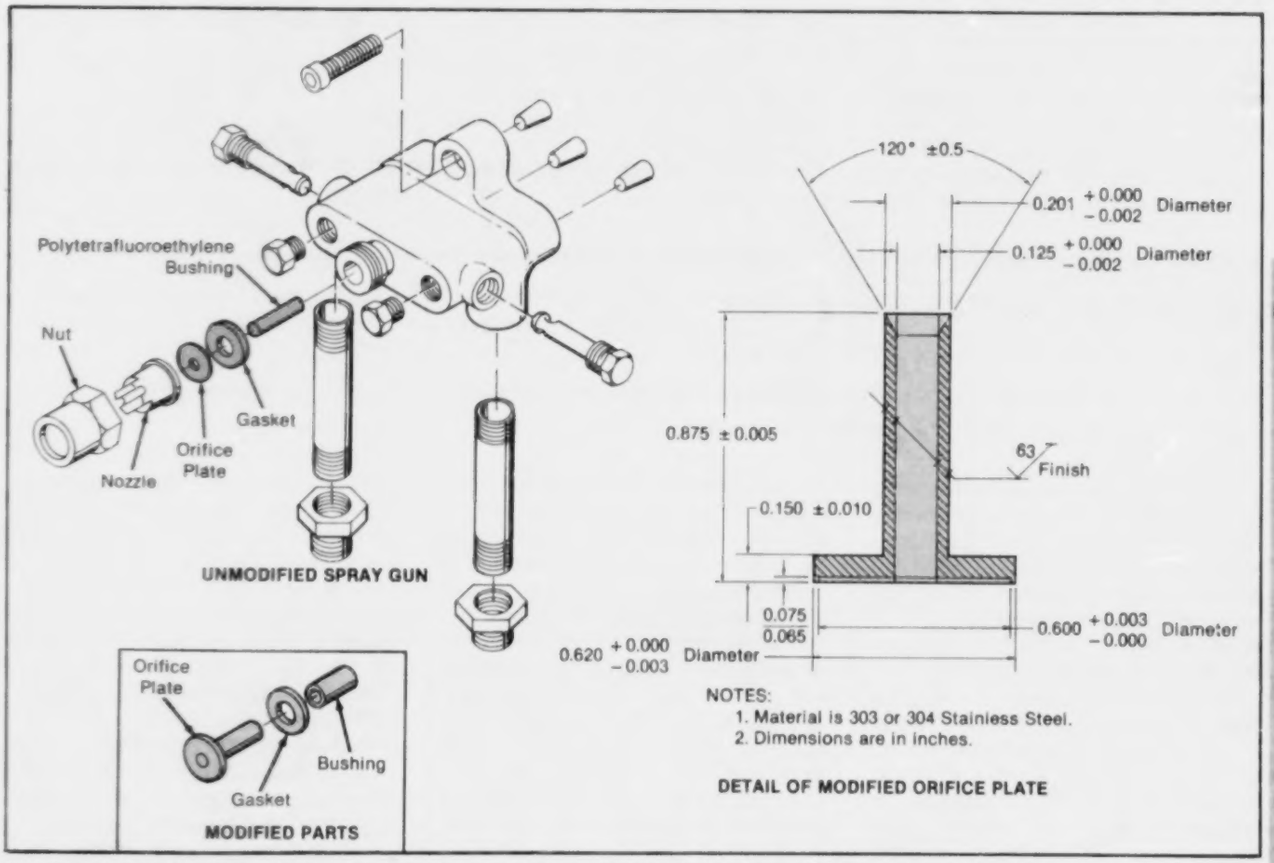
The erratic spray pattern of a commercial spray gun is changed to a repeatable one by a simple redesign of two parts. Such an improvement may be useful in many industrial applications requiring repeatable spray patterns. These might include the spraying of foam insulation, paint, other protective coatings, detergents, abrasives, adhesives, process chemicals, or fuels.

In the unmodified spray gun (see figure), the orifice plate lies between the gasket and the nozzle. The gasket, orifice plate, and nozzle are held together inside a specially shaped nut. The inside diameter of the nut is 0.625 in. (15.88 mm), while the outside diameters of the nozzle and orifice plate are both 0.590 in. (14.99 mm). The nozzle and orifice plate thus fit loosely in the nut and can slide laterally up to a maximum misalignment of 0.035 in. (0.89 mm).

The spray pattern depends critically on the alignment between the orifice and the nozzle. In the unmodified gun, the looseness of these critical parts causes the spray angle to vary several degrees in an unrepeatable manner. In the modified gun, alignment is assured by reworking the polytetrafluoroethylene bushing, providing the orifice plate with a shank that fits in the bushing, and increasing the outer diameter of the orifice plate to 0.620 in. (15.75 mm). This combination of changes assures a repeatable spray pattern.

This work was done by W. C. Cunningham of Martin Marietta Corp. for **Marshall Space Flight Center**. *For further information, Circle 91 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28110.



The **Unmodified Spray Gun** produces an erratic spray because of lateral misalignment between the orifice plate and the nozzle. In the modified spray gun the orifice plate and the polytetrafluoroethylene bushing are redesigned to assure centering and alignment with the nozzle.

Flow Injector Would Keep Slurry From Settling

Costly pipeline choking would be reduced or prevented.

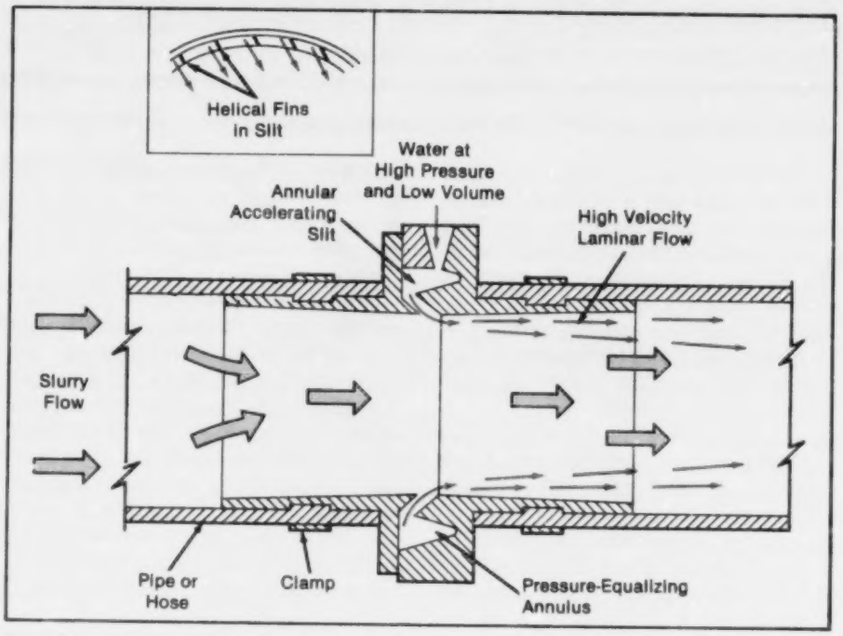
NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed ring nozzle may help to prevent the choking of coal-slurry pipelines. Intended originally for use in coal mines, the nozzle concept should be generally applicable to short-haul slurry pipelines where high-pressure water (or other slurry fluid) is available.

Where the flow rate is insufficient, the particles of a slurry tend to settle out of the fluid, forming a solid slug that blocks the pipeline. In some instances, it is necessary to break the pipeline open to remove the blockage.

The ring nozzle helps to prevent such blockages by enabling the injection of extra water or other fluid to augment the flow near the wall. A relatively small volume of water at high pressure is accelerated through an annular slit into the pipe (see figure), forming a laminar-flow boundary layer that entrains a large volume of slurry. Helical fins in the accelerating slit impart a rotation to the injected and entrained flows, thereby enhancing the ability to prevent settling of the slurry particles.

The injection concept is expected to be efficient in energy and applicable to coal-slurry conduits at any angle from horizontal to vertical. For maximum effectiveness, injection nozzles would be placed at intervals along a slurry line.



Extra Water is injected into the flow near the wall of a slurry pipe to keep the slurry particles from settling and blocking the pipe.

The separations between nozzles, water pressures, injection angles, and other parameters would be chosen in accordance with the haulage conditions of the slurry system.

This work was done by Edward V. Lewis of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 90 on the TSP Request Card.*
NPO-16186

Liquid/Gas Vortex Separator

Gas is removed from a liquid in a tank.

Lyndon B. Johnson Space Center, Houston, Texas

A liquid/gas separator vents gas from a tank of liquid that contains gas randomly distributed in bubbles. The device, which resembles a cyclone separator, was conceived for use in zero gravity. On Earth an augmented version could be used to separate gas from a liquid when gravitation alone is insufficient.

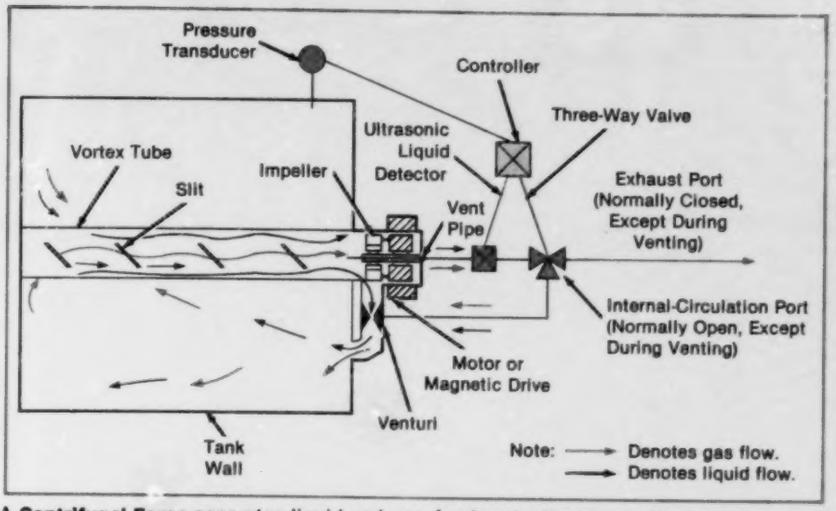
The separator includes a spinning impeller to impart rotation to the liquid/gas mixture in a tube in the tank (see figure). In the resulting vortex, liquid is thrown to the tube wall by centrifugal force. The gas in the center of the tube is almost free of liquid. The gas is withdrawn from the center through a vent pipe.

A three-way solenoid-operated valve at the outlet end of the vent pipe either lets the gas escape or else closes the outlet and diverts the flow back into the tank through a venturi tube in the liquid-recirculation path. The main liquid flow in the venturi causes the suction that drives this secondary flow. An ultrasonic transducer detects such liquid as might remain in the gas and be drawn into the vent pipe and sends a signal to the valve controller to turn the valve to the recirculating, nonventing position. This feature reduces loss of the liquid.

A pressure sensor in the tank is also connected to the valve controller. When the pressure has been reduced to a preset level, the controller stops the venting by turning the valve to the recirculating position.

The vortex tube has slits through which the liquid/gas mixture flows to and from the rest of the tank. The inside of the vortex tube is polished or coated for smoothness to minimize friction between it and the liquid, thus increasing the efficiency of vortex generation. The outside of the tube is coated with polytetrafluoroethylene to make it unwettable, thereby facilitating the movement of gas.

The impeller is powered by an encapsulated permanent-magnet rotor; the stator is outside the tank and separated from the rotor by a pressure barrier. Leakage through rotary seals is thus eliminated. The impeller could also be turned through a magnetic drive like those used commonly on industrial



A **Centrifugal Force** separates liquid and gas, forcing the liquid out of the vortex tube through the venturi tube. Gas is vented through the exhaust port. When liquid is detected in the vent tube, the exhaust port is closed, and the liquid/gas mixture in the vent tube is drawn back into the tank through the venturi.

pumps.

The continuous circulation of the liquid tends to produce a uniform temperature throughout the tank. Liquid-quantity gauges will therefore produce more accurate readings.

This work was done by Brian G. Morris of **Johnson Space Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 29]. Refer to MSC-21058.

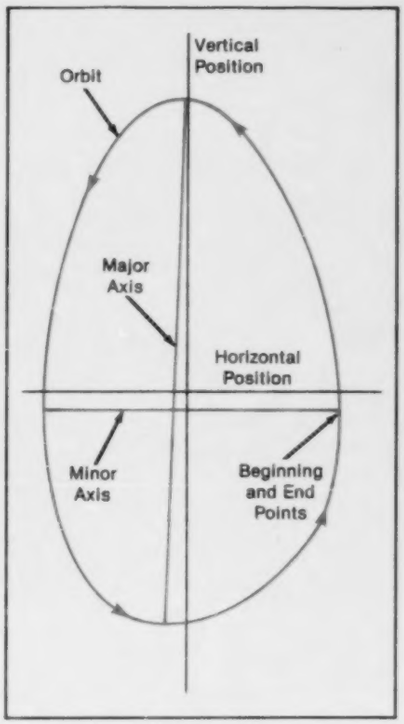
Automated Rotating-Machinery Analysis

System provides data and plots of motion.

Marshall Space Flight Center, Alabama

A computer-controlled automatic system processes accelerometer data from rotating machines, producing a mathematical description and graphical display of shaft motion. The program saves processing time, readily identifies the type of motion (circular, looped, or elliptical), provides annotated assessments to assist in failure analysis, alerts the user to look for distinctive characteristics of the machinery, and creates informative plots.

The system digitizes the data from two orthogonally positioned transducers, thereby obtaining histories of motion along the transducer axes. It calculates the time required for one shaft orbit and determines the oscillation frequencies above and below the shaft rotational speed, while compensating for distortions



A **Shaft Orbit** is printed out as a plot of successive positions computed from accelerometer measurements. Additional plots (not shown) are of power versus frequency and rotational cycle.

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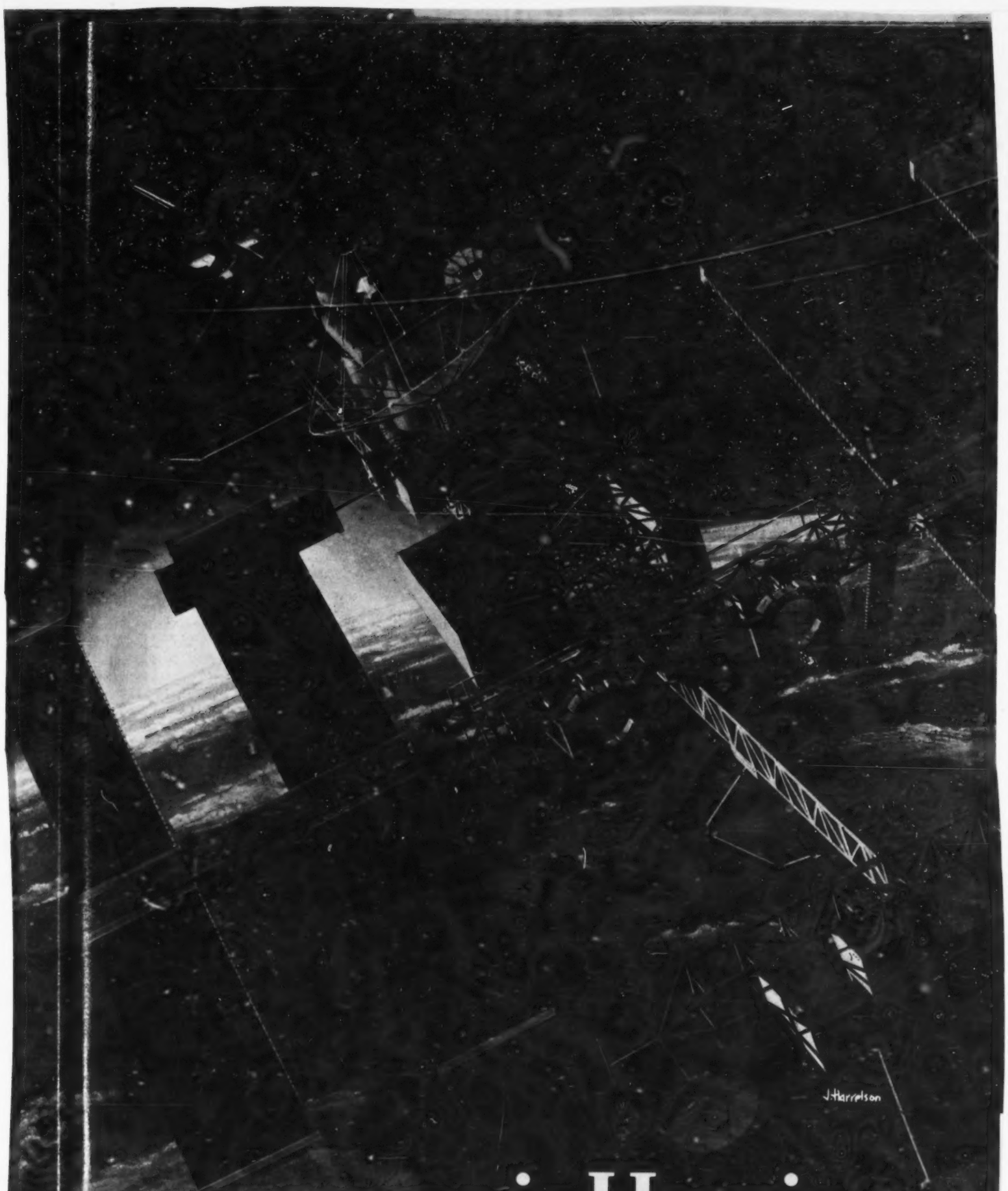


our name is Harris.

introduced by low signal-to-noise ratios. The program finds the major and minor axes of the shaft orbit. It prints out single and multiple orbits (see figure) and shows the motion history and the power spectrum of the dynamic data. With the system, the user can analyze rotor stability and evaluate unbalance response, impact, and rubbing caused by nonrotating machinery.

This work was done by J. E. Clark of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-19912

Bidirectional, Automatic Coal-Mining Machine

Deadheading and other inefficiencies would be eliminated.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed coal-mining machine would operate in both the forward and reverse directions along a mine face. The new design would increase efficiency and productivity, because it would not stop cutting as it retreated to the starting position after completing a pass along the face. To further increase efficiency, the automatic miner would carry its own machinery for crushing the coal and feeding it to a slurry-transport tube.

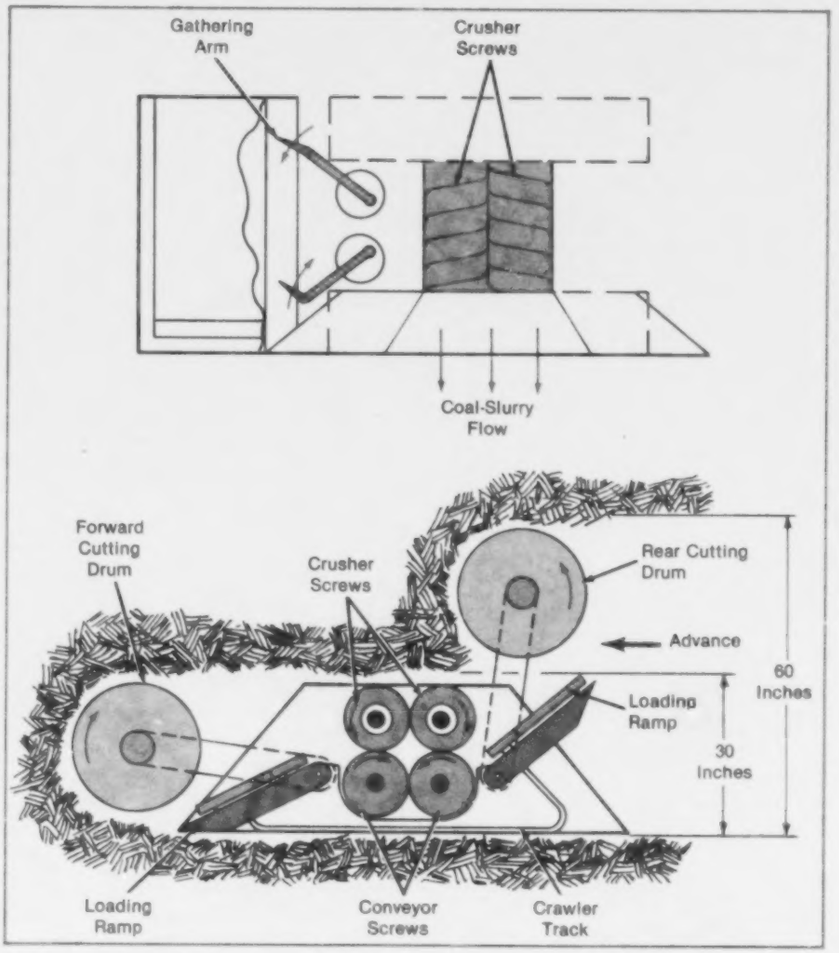
According to the concept, the mining machine cuts coal with two cutting drums as it advances on crawler tracks. The aft drum is elevated above the forward drum so that it has access to fresh material (see figure). With this arrangement, the machine frame must be no higher than the forward-drum cutting diameter; since the machine will be automatically controlled, there will be no difficulty in designing it for a low profile — no cab for an operator will be necessary.

The coal cut by the aft drum falls on a loading apron at the rear of the machine. The apron simply feeds coal by gravity to crushing screws at the center of the machine.

The coal cut by the forward drum falls to the mine floor, where oscillating gathering arms scoop and push it up the forward-loading ramp of the machine into the crushing screws. The screws crush the coal from both forward and aft cutters to a size that can be handled by the slurry-transport system. The machine adds water at low pressure to the crushed particles, and the lower screws convey the mixture into a slurry-haulage tube on the side of the machine opposite the mine face.

When the machine reaches the end of a pass, the relationship of the drums is reversed. The aft drum is lowered, and the forward drum and its loading ramp are raised so that they can continue cutting and feeding the slurry tube as the miner reverses direction and retreats. The only interruption is that for the machine to maneuver in the entry passage to cut farther into the face; this maneuver would be controlled automatically or remotely by human operators.

This work was done by Earl R. Collins, Jr., of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 26 on the TSP Request Card.*
NPO-15860



The **Dual-Drum Mining Machine** cuts coal in two layers, crushes it, mixes it with water, and feeds it as a slurry to a haulage tube. At the end of a pass, the forward drum is raised so that it becomes the rear drum, and the rear drum is lowered, becoming the forward drum for the return pass.

Heat Radiators for Electromagnetic Pumps

Carbon/carbon composite radiators withstand high temperatures.

A report proposes the use of carbon/carbon composite radiators in the electromagnetic coolant pumps of nuclear reactors on spacecraft. Carbon/carbon composite materials can function well at temperatures in excess of 2,200 K. Aluminum, which would normally be used, has a melting temperature of only 880 K.

Two configurations have been proposed. In the first case, the composite radiator structure would be bolted and clamped to the three outer ends of the stator-core laminations of a polyphase, annular linear induction pump. The operating temperature would be about 600 K. The radiator structure would conduct heat from the stator core and windings to an outside shield, from which the heat would be radiated into space.

Heat from the portion of the core away from the radiator would be conducted circumferentially around the core in the copper stator windings and into the part of the core near the radiator. Heat that leaks into the stator from the heat-transfer fluid being pumped, including heat induced by the oscillating magnetic field of the pump, joins the thermal flux conducted from the stator to the radiator. In the second case, a composite structure would serve as the waste-heat radiator of an integral thermoelectric generator that supplies power to a thermoelectromagnetic coolant pump. The maximum operating temperature would be 825 K. In both cases, the radiators would be made large enough, not only to radiate heat adequately, but also to shield the equipment from meteorites and other debris.

This work was done by Robert J. Campana of GA Technologies, Inc., for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Electromagnetic Pump Heat Radiators," Circle 81 on the TSP Request Card.*
NPO-16458

Long, Thin, Deployable Mast

The mast extends to 25 times its original length.

A report describes a 15-m-long deployable mast and discusses the design and development that went into making the product. Only 0.6 m long when stowed, the mast extends itself to its full length. Although the extended mast is long and narrow, with an aspect ratio of 67:1, it resists bending. Its predicted bending strength and bending stiffness are 4,700 N-m and 1.3×10^6 N-m^2, respectively. Its mass per unit length is 3.43 kg/m.

The mast consists of longerons braced by battens and diagonal filaments. The components are made of glass-reinforced epoxy. In the stowed condition, the 15-m-long longerons are coiled in a tight helix, with the battens and filaments nested between coils. When restraining rods are released, the longerons uncoil and the mast extends. A lanyard controls the rate of uncoiling so that the longerons do not snap immediately to their full length and overstress the structure. The lanyard is also used to retract the mast by pulling the tip toward the base; the longerons again coil and compress the structure to its drumlike stowed form.

A base support, end plate, and winch were built for testing the mast in a 1 g environment. In such testing, the mast should be mounted with its base up and should be extended downward to avoid damage.

This work was done by Laurence A. Finley of Astro Research Corp. for **Marshall Space Flight Center**. *To obtain a copy of the report, "Large-Diameter Astromast Development, Phase II — Final Report," Circle 11 on the TSP Request Card.*
MFS-27088

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Fabrication Technology

Hardware, Techniques, and Processes

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Making Highly Pure Glass Rods

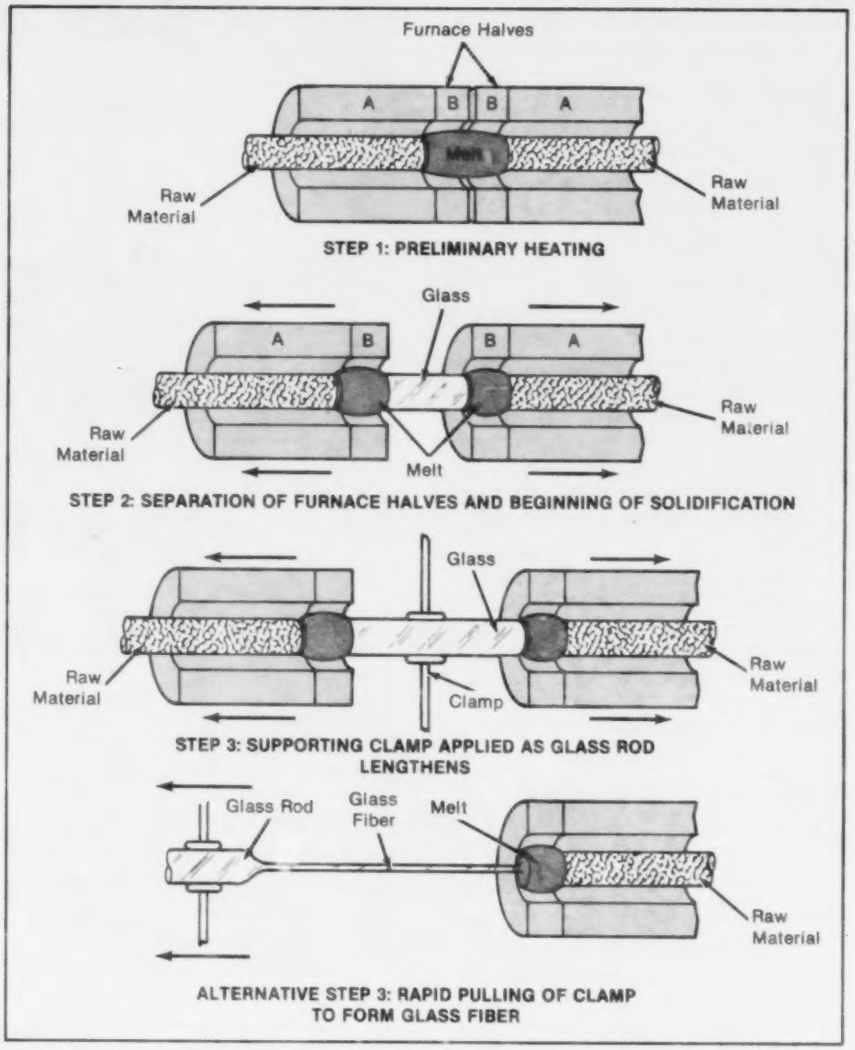
A quasi-containerless process might be used to make optical fibers.

Marshall Space Flight Center, Alabama

A proposed quasi-containerless method for making glass rods or fibers would minimize the contact between the processing equipment and the product. The method would allow a greater range of product sizes and shapes than have thus far been achieved in experiments on containerless processing.

Most research and development on containerless processing involves levitating materials by aerodynamic or acoustic forces or allowing materials to fall through long tubes while their temperatures are varied. With these methods, the specimens assume a spherical shape becuse of surface tension in the molten materials. In addition, the specimens are necessarily small because of the physical limitations of the equipment and the low thermal conductivities of the melts, which limit the heating and cooling rates in the containerless environment.

In contrast, the new quasi-containerless concept would enable the formation of glass rods. The rod diameter would be limited only by the amount of power available to melt through the polycrystalline raw material. To a large extent, the method would retain the advantages of true containerless processing. It would



A Molten Zone Is Established in a polycrystalline rod. Furnace sections are separated, and a glass rod solidifies between them. A clamp then supports the solid glass as it grows in length. Pulling the clamp rapidly away from the melt draws a glass fiber. The fiber diameter could be controlled by adjustment of the pulling rate.

eliminate contamination of the melt by a crucible. It would also eliminate premature nucleation by contact with a container and would thus permit deep undercooling and unusual glass compositions.

According to the concept, the starting material is a rod of either a polycrystalline or gel precursor of the amorphous glass product. In rod form, the precursor is placed in a furnace of two movable halves, each containing two temperature zones (see figure). The walls of zones A are heated to just below the melting point of the rod. The walls of zones B are adjusted at the junction of the halves so that they melt a short zone of the rod. (As in standard floating-zone refining, the rod may be pulled through the furnace a few times to become purified and have uniformly distributed dopants.)

The sections of the furnace are slowly separated, moving the molten regions outward along the rod. The central melt cools by radiation and gradually solidifies as a glass. Premature nucleation is avoided because nothing contacts the cooling material except the molten zones, which have the same composition as that of the cooling material.

In most glasses, increasing temperatures cause the surface tensions to decrease. Therefore, bubbles in the newly formed glass melt would ordinarily tend to migrate out of the cooler solidifying rod toward the hotter melts in zones B.

Initially, the solidified glass must be supported by the surface tension of the molten zones. If the process is conducted in low gravity, longer unsupported regions are possible. External clamps may be extended to brace the glass rod after it has begun to solidify. Such a clamp may be used to draw the rod into an optical fiber, as shown in the figure.

This work was done by Robert J. Naumann of **Marshall Space Flight Center**. *For further information, Circle 17 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28090.

Improved Joint Design for Box-Stiffened Panels

Photoelastic models are used to visualize stress concentrations.

Langley Research Center, Hampton, Virginia

An aircraft fuselage structure must contain an internal pressure and carry the fuselage compressive loads. Optimization techniques can be used to find efficient stiffened structures to carry the compressive loads, but the internal pressure induces cyclic tensile loading transverse to the stiffeners that will determine the structural fatigue life. Therefore, in addition to carrying the compressive loads without buckling, an efficient stiffened fuselage wall must demonstrate an adequate cycle life. Mass and strength analyses and system requirements have identified a titanium-box-stiffened-skin wall (see Figure 1) as a candidate for the lightweight fuselage of a pressurized vehicle.

Test results identified a severe stress concentration at the junction of the box stiffeners with the panel skin. The stress concentration would limit the number of cycles to failure below the desired service life of 10^6 cycles at 50,000 psi (340 MPa). Photoelastic models of the stiffener-to-skin joint were used to identify quickly modifications to the joint that would lower the severity of the stress concentration. Results with various photoelastic models cut from polyurethane sheet led to a novel diffusion-bond joint with a reduced stress concentration. For verification, titanium test specimens of this joint indicated that the desired cycle life could be achieved at the desired stress level with the box-stiffened-skin panel.

Photoelastic model A in Figure 2, of the standard doubler under a tensile load, shows a severe stress concentration at the bottom of the notch. Model B of the flanged doubler shows a stress concentration that also is unacceptable. Model C, a chemically milled transition with a generous radius, shows a

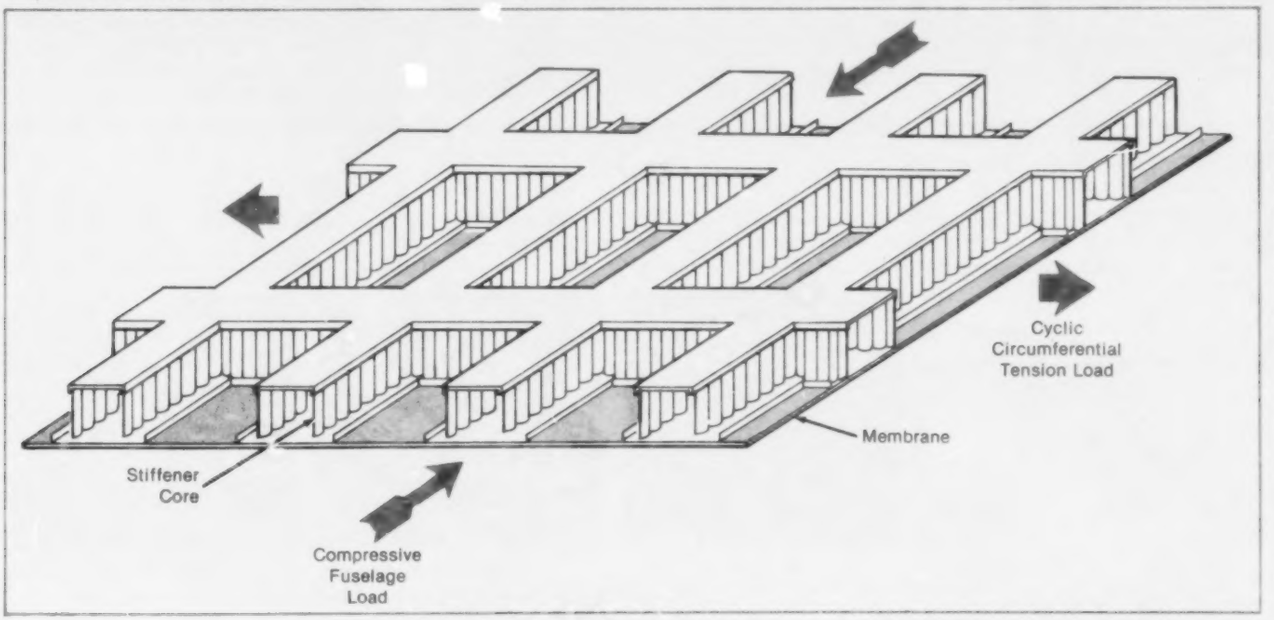


Figure 1. **The Titanium-Box-Stiffened Skin** is a candidate for use in the walls of pressurized fuselages.

stress concentration that is greatly reduced by the large radius transition, with an area of nearly zero stress at the raised corner of the land.

Model D duplicates a proposed joint in which the stiffener lower cap would be diffusion bonded to the chemically milled transition such that the bond line ends at the corner of the land, where the stresses are the lowest. Results from model D show that this location for the sharp notch of the lower cap-to-skin joint is out of the area of stress concentration that affects the cycle life. Additionally, the photoelastic-model results show that decreasing the thickness of the land under the stiffener reduces the induced bending stresses caused by a discontinuous load path and reduces the stress concentration for this improved doubler-joint design.

Titanium-fatigue-coupon test results demonstrated a potentially significant loss in fatigue life associated with the stress concentrations found in the photoelastic models. Titanium fatigue specimens with varying geometric details for the improved doubler-joint design show that increased land depth and no flange overhang increase bending stresses in the joint, adversely affecting cycle life. A refined joint with a flange overhang and a thin land gives a design that provides the desired 10^6-cycle life at 50,000 psi (340 MPa). Results from symmetric specimens show that further reductions in load-path discontinuity could improve this cycle life at even higher stresses.

This work was done by Randall C. Davis of **Langley Research Center** *and Paul L. Moses of PRC Kentron, Inc. Further information may be found in NASA TP-2480 [N85-33537/NSP], "Joint Design for Improved Fatigue Life of Diffusion-Bonded Box-Stiffened Panels."*

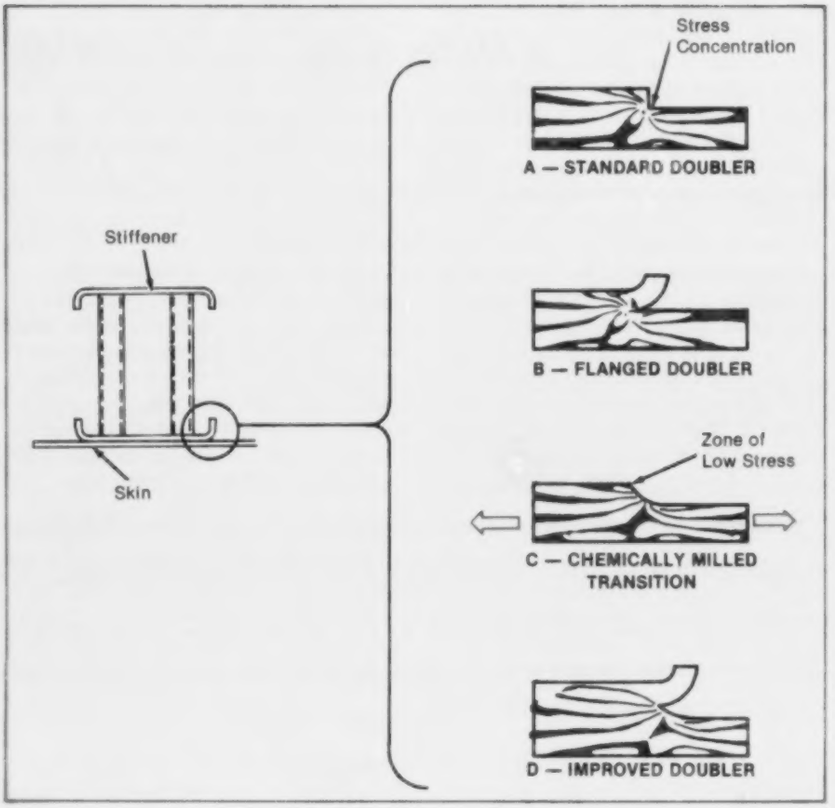


Figure 2. **Photoelastic Models** make visible the stress-concentration patterns in the stiffener-to-skin junctions.

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LAR-13460

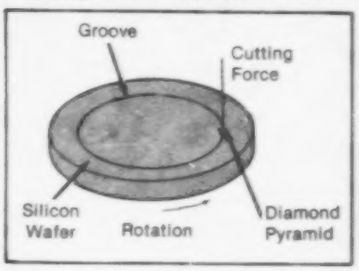
Smoother Scribing of Silicon Wafers

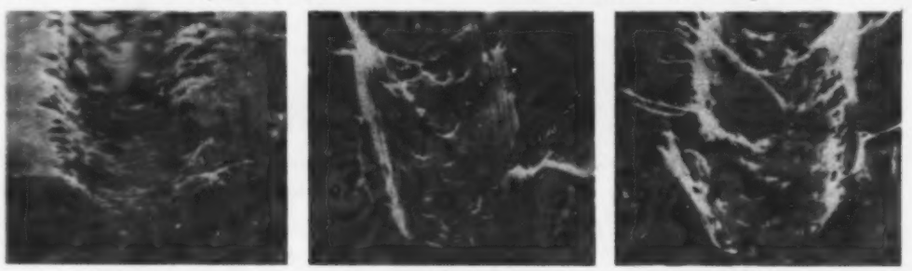
Ethanol alters the normally brittle character of the silicon wafers into a more ductile material for smoother scribing.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed new tool may be used to scribe silicon wafers into chips more smoothly than was possible before. The new scriber produces a surface that appears ductile. The scribed groove cuts have relatively smooth walls.

The scriber would consist of a diamond pyramid point on a rigid shaft. Ethanol would flow through the shaft and





With Water | With Ethanol | With Acetone

SCANNING-ELECTRON MICROGRAPHS OF GROOVES

A **Groove Is Cut** in a 3-in. (7.62-cm) wafer by a diamond point. With water as a lubricant, the groove is rough and uneven; with ethanol, the groove is smoother and more sharply defined. Intermediate results are obtained with acetone.

around the point, like ink in a ballpoint pen.

Ethanol has a significantly different effect for scribing silicon than water, which is used in conventional diamond scribers. The ethanol apparently adsorbed by the silicon surface softens it for cutting. The effectiveness of ethanol as a scribing lubricant was discovered in a study of abrasion mechanisms in silicon. Wafers of polished silicon were rotated under a stationary diamond pyramid while immersed in various fluids (see figure). The resulting grooves were examined with a scanning electron microscope. For a given cutting speed and force on the diamond, the water-lubricated groove showed rougher, uneven walls, as compared with the ethanol-lubricated groove.

This work was done by Steven Danyluk of the University of Illinois for Caltech and **NASA's Jet Propulsion Laboratory**. *For further information, Circle 19 on the TSP Request Card.* *NPO-16568*

Robotic Vision for Welding

The view from the welding head is used to control the welder.

Marshall Space Flight Center, Alabama

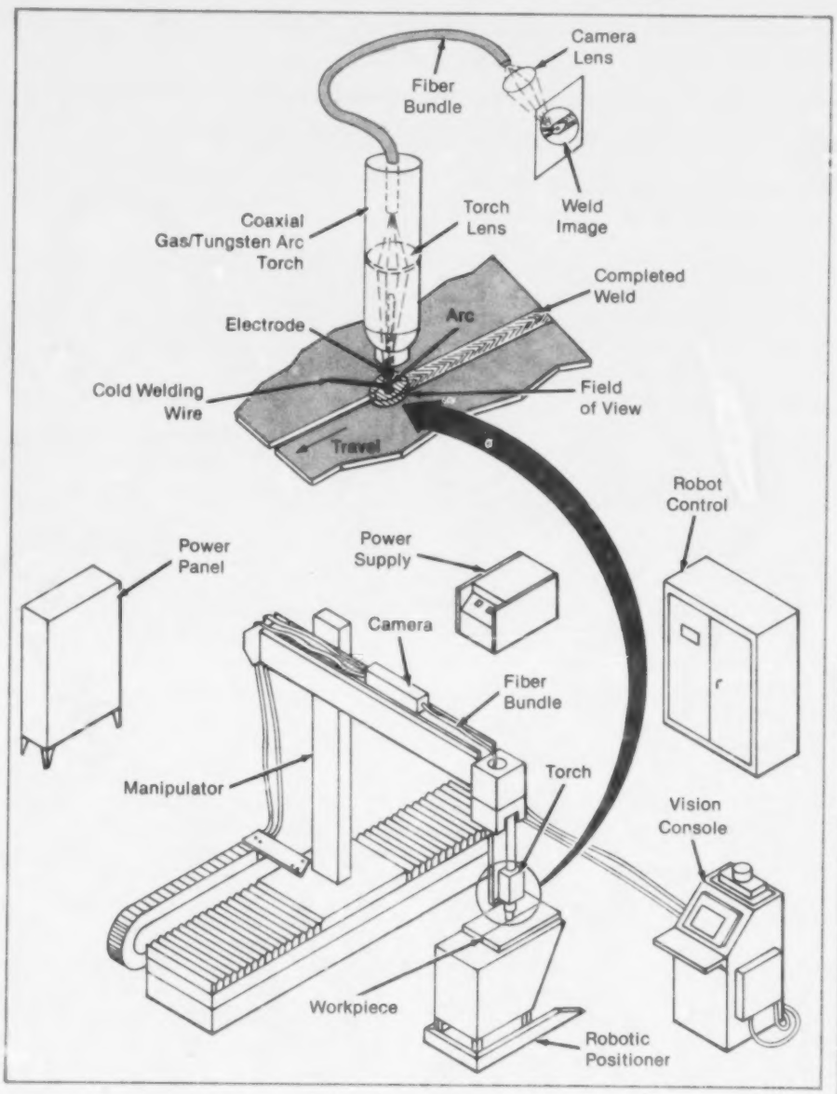
A vision system for a robotic welder looks at a weld along the axis of the welding electrode. The vision system gives the robot a view of most of the weld area, including the yet-unwelded joint, the weld pool, and the completed weld bead.

The viewing optics are contained within the gas cup of a gas/tungsten arc welder (see figure). The optical components are thus protected from the heat, corrosive gas, and spattered metal just outside the cup. Moreover, the components do not interfere with the workpiece or hinder tool movement. Although the optical components are shielded by the electrode from the intense, direct light rays from the core of the arc, they nevertheless view the bright light cast on the weld area and from it produce a detailed image. A control computer analyzes the changing image in real time to guide the robot and adjust such welding parameters as current and wire feed.

A lens in the gas cup focuses an image of the weld area onto the end of a fiber-optic bundle. The torch lens is mounted in a ring having 30-mm outside diameter. A filter window protects the lens and the fiber-optic bundle from the welding environment; the window passes wavelengths around 800 nanometers. It absorbs the visible and ultraviolet radiation from the arc and the longer infrared wavelengths from the incandescent weld pool. Cooling water flowing through the torch body removes the heat of the absorbed radiation. The window also blocks fumes and spattered metal.

The fiber-optic bundle is composed of more than 100,000 glass fibers, each 10 to 12 μm in diameter and 7 ft (2.1 m) long. The fibers are arranged in a circular matrix. At each end, the bundle is encased in a stainless-steel ferrule, and the end surfaces are ground and polished. The bundle is sheathed in an oil-filled plastic tube. The packaged bundle is highly flexible to allow fast and wide-ranging movement of the robot arm and torch.

The bundle carries the image to a video camera atop the robot-manipulator boom. A cable carries the video signal to a control console, where the raw signal is processed into analog and digital video signals for the computer.



Protected Within a Welding-Torch Body, a lens and fiber bundle give a robot a closeup view of a weld in progress. Relayed to a video camera on the robot manipulator frame, the weld image provides data for automatic control of the robot motion and the welding parameters.

The computer is based on an 8-bit, 1-MHz microprocessor. It has 96 kilobytes of memory and uses 54 kilobytes of software, written in Assembler language. The software includes 30 kilobytes of specially written programs for processing images, controlling the robot, and interacting with users. The software consists of the following four modules:

1. The vision-system module supports basic system operation.
2. The image-processing system module provides real-time processing of video images to extract the locations of the weld features.
3. The "weld teach" module handles programming of the robot for specific welding jobs.
4. The vision-utilities module accommodates communication with remote systems, controls video recording of welding, and handles other supporting functions.

From the processed image data, cross-seam control commands are generated for one-dimensional control of the robot path to center the pool on the weld joint. A signal representing the width of the joint is generated and used to control the feed of welding wire into the weld. A signal representing the weld-pool width is used to control the welding current.

This work was done by Richard W. Richardson of the Ohio State University Research Foundation for **Marshall Space Flight Center.** *For further information, Circle 121 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

James B. Wilkens, Patent Administration
The Ohio State University Research Foundation
1314 Kinnear Road
Columbus, OH 43212.

Refer to MFS-27119, volume and number of this NASA Tech Briefs issue, and the page number.

Flexible Diaphragm Withstands Extreme Temperatures

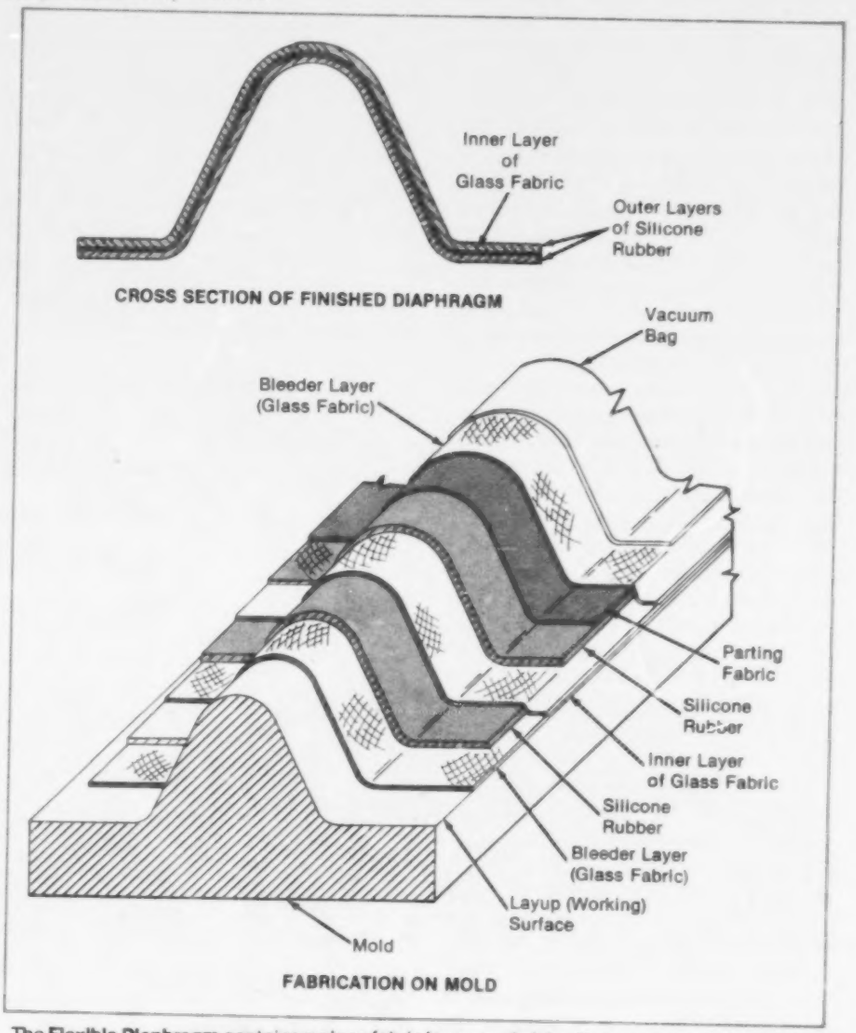
This diaphragm seals and retains its flexibility from −200 to +600 °F (−129 to +316 °C).

Lyndon B. Johnson Space Center, Houston, Texas

A diaphragm seal retains flexibility throughout the temperature range of −200 to +600 °F (−129 to +316 °C). The diaphragm is durable, simple, versatile, and relatively inexpensive to manufacture. Developed specifically for the Space Shuttle orbiter, the diaphragm should be suitable for refrigeration seals, autoclaves, storage lockers, and other sealing applications subjected to extreme temperature differentials.

The diaphragm (see figure) consists of two outer layers of silicone rubber on an inner layer of glass fabric impregnated with an adhesive. The fabrication process involves the following sequence of steps:

1. An aluminum male layup mold, machined 2 percent oversize to allow for the shrinkage of the silicone rubber, is cleaned with 1,1,1-trichloroethane.
2. A continuous coat of adhesive is sprayed on the working surface and allowed to develop a good tack.
3. To aid the removal of air during vacuum bagging, a first bleeder layer of glass fabric is applied smoothly to the adhesive, with the warp in the long direction of the mold and extending beyond the diaphragm edge.
4. The bleeder fabric is coated and saturated with a release agent; for example, a fluorocarbon parting agent.
5. The first layer or sheet of calendered, uncured silicone rubber is applied without wrinkles to the bleeder fabric. Good results have been obtained with calendered, uncured methyl phenyl siloxane polymer sheet 0.030 in. (0.076 cm) thick.
6. The inner layer of continuous glass-



The Flexible Diaphragm contains a glass-fabric layer sandwiched between two silicone-rubber layers.

fabric reinforcement is applied without wrinkles, splices, or folds to the first layer of silicone rubber, maintaining the warp direction and extending beyond the edge of the silicone rubber.

7. The reinforcing layer is impregnated with diluted silicone-rubber adhesive primer.
8. The second silicone-rubber layer is applied.
9. A layer of fluorocarbon-coated or other parting fabric is applied to the second layer of silicone rubber.
10. The parting fabric is covered with a layer of bleeder fabric extending beyond the edge of the silicone rubber.
11. A vacuum bag is sealed to the layup mold over the preceding layers.
12. A vacuum is slowly applied between the vacuum bag and the mold, and the assembly of layers is cured at 345 °F (174 °C) with a pressure of 75 psi (520 kN/m^2) applied externally to the vacuum bag.
13. The assembly is cooled, the vacuum and pressure are released, and the finished diaphragm is removed from the first bleeder layer and the parting layer.
14. The diaphragm flanges are trimmed to the finished dimensions.

This work was done by Guillermo Lerma of Rockwell International Corp. for **Johnson Space Center**. *For further information, Circle 5 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Flight Center [see page 29]. Refer to MSC-20797.

Repairing Foam Insulation

Holes are filled without introducing voids.

Marshall Space Flight Center, Alabama

Large holes in polyurethane foam insulation are repaired reliably by a simple method. Little skill is needed to apply the method, and it can be used for overhead repairs as well as for those in other orientations.

The method was developed for replugging pull-test holes in the insulation on a tank: After the insulating polyurethane foam has been applied, it must be tested to determine its adherence to the tank. This is a destructive test in which a plug of foam is removed.

In the previous repair procedure, liquid foam was placed in a hole and covered with tape while it cured. The resulting plug usually contained large voids of entrapped air. This was particularly true for holes in overhead and sidewall insulation because air could not escape through the solid surroundings in these orientations.

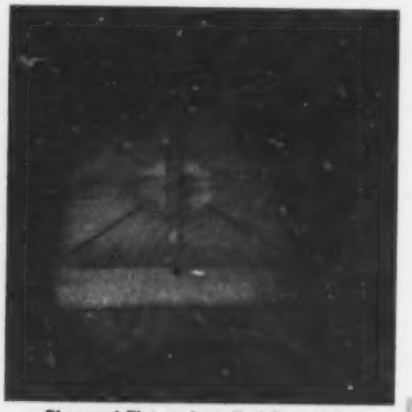
In the new repair method, a two-piece plug of foam insulation is inserted in the hole and held in place with a mounting fixture (see figure). A fresh batch of foam is mixed and, while still liquid, is injected through the plug. The liquid foam is allowed to cure and harden into a contiguous mass that joins the plug to the surrounding insulation and the substrate. After about 2 hours, the mounting fixture is removed. The protruding end of the plug and excess foam are trimmed away.

The method was demonstrated by filling 40 holes in foam 1 ½ to 2 in. (3.8 to 5.1 cm) thick. All repaired holes met the inspection requirement that a repair area contain no more than seven voids, with no more than one void greater than 0.3 in. (0.8 cm) and none greater than 0.5 in. (1.3 cm).

This work was done by J. M. Corbin and D. F. Buras of Martin Marietta Corp. for **Marshall Space Flight Center**. *For further information, Circle 61 on the TSP Request Card.*

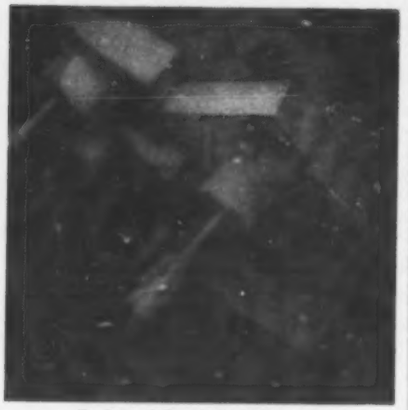
Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 29]. Refer to MFS-28109.

Two-Piece Plug and Mounting Fixture



Plug and Fixture Installed Over Hole

Injection of Foam



Curing of Completed Repair

A Plug Is Positioned in the Hole to Be Filled and held in place with a mounting fixture. Fresh liquid foam is injected through the plug to bond it in place. As the foam cures and expands, it displaces the plug outward. This protrusion is later removed.

Liquid-Dopant Fabrication of Solar Cells

Cells are as efficient as those produced by gaseous diffusion.

NASA's Jet Propulsion Laboratory, Pasadena, California

Liquid dopants and liquid masks are used to produce the front and back junctions of solar cells. The resulting cells are equal in efficiency to those fabricated by the more-expensive gaseous-diffusion technique.

To begin the fabrication of the back junction, liquid boron dopant is applied to the back of dendritic-web silicon, and a liquid mask is applied to the front. Then the wafer is baked at 200 to 400 °C for 15 minutes to remove excess solvents. The dopant is then thermally diffused into the silicon from the back surface. After diffusion, the mask and the excess dopant (now in the form of a glass) are removed.

To begin the fabrication of the front junction, liquid phosphorus dopant is applied to the front of the wafer, and a liquid mask is applied to the back. Again, the wafer is baked at 200 to 400 °C for 15 minutes to remove excess solvents. The phosphorus dopant is then thermally diffused into the silicon. The diffusion glass is then removed.

This work was done by Paul Alexander, Jr., of Caltech for **NASA's Jet Propulsion Laboratory** *and Robert B. Campbell of Westinghouse Corp. For further information, Circle 100 on the TSP Request Card.*
NPO-16652

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Development of Graphite/Epoxy Corner Fittings

Various layup patterns are evaluated.

A report documents a development project aimed at improving the design and load-carrying ability of a complicated corner fitting for an optical bench. The new fitting is made of graphite filaments in an epoxy-resin matrix. The composite material was selected as a replacement for titanium because it is lighter and because its dimensions change little with temperature variations. Previous efforts to use graphite/epoxy had to be abandoned in favor of titanium because the composite material was too weak.

The objectives of the project were to evaluate layup changes to increase the ultimate strengths of the parts, to develop basic data on the material, to establish analysis methods, and verify the design and analysis by testing full-size parts. Four different fitting designs were executed, each differing from the other by the arrangement, or layup of the composite material.

The unsuccessful graphite/epoxy fittings that preceded the titanium version failed by fracture along the laminate splice lines. These lines lay along the edges of the fitting. In the new graphite/epoxy fittings, the same laminate material, fiber orientation, resin content, and basic dimensions were used. The layup patterns, however, were modified to relocate the splice lines away from the corners.

Strain-gauge measurements were made while the fittings were subjected to static-load tests. The ultimate failure load varied from a low of 2,229 lb (9,915 N) to a high of 4,492 lb (19,981 N). The test results did not correlate closely with the predictions of finite-element structural analysis using classical laminate theory. Test results also did not correlate closely among different fittings of the same configuration. The low correlation has been tentatively attributed to the lack of quality control in fabrication. This kind of variation among units is typical of composite materials.

This work was done by Gwyn Faile, Rose Hollis, Frank Ledbetter, Juan Maldonado, Jim Sledd, Jim Stuckey, Gerald Waggoner, and Erich Engler of **Marshall Space Flight Center**. *Further information may be found in NASA TM-86512 [N85-32147/NSP], "Development and Test of Advanced Composite Components."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 101 the the TSP Request Card.
MFS-27129.

Stand By for a Wealth of Information!

Indices to past NASA Tech Briefs will soon be available from NASA. The 1981 Index will be prepared first, with 1982 to the present soon to follow.

Prices and ordering information will be published in future NASA Tech Briefs.

Estimating Wall-Induced Velocities in Wind Tunnels

Wall effects are calculated from upwash distributions.

Ames Research Center, Moffett Field, California

Estimates of wall effects in a two-dimensional wind tunnel are obtained using upwash measurements on two contours near the test model. The method is derived from a combination of prior techniques that correct for wall effects.

The improved method is limited to flows describable by linear equations. Measured flow perturbations are assumed to be superpositions of the perturbations resulting from the model in free air at a corrected airspeed and angle-of-attack, plus perturbations produced by the tunnel walls. The mathematical assumptions are valid if wall-induced velocities are uniform near the model: Test conditions become increasingly uncorrectable as wall-induced velocity gradients grow near the test model.

The wind-tunnel geometry is shown in the figure. The model is enclosed by two integration contours, each consisting of two horizontal lines extending an infinite distance upstream and downstream, joined at their ends by vertical lines. Since the contribution of the vertical lines to the flow field is infinitesimal due to their infinite distance from the model, the contours are treated as consisting of the horizontal lines alone. The lines closest to the model are called "source levels," while the outer lines are called "field levels."

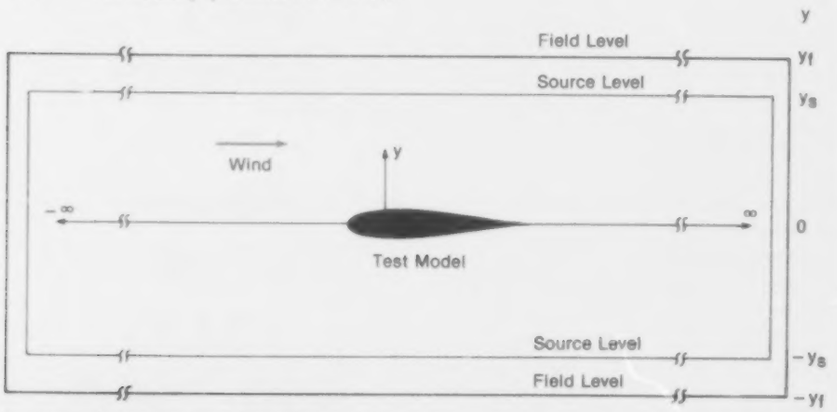
The Schwarz formula (which is a linear transformation) enables the calculation of the wall-induced upwash along the tunnel axis ($y = 0$) from the symmetric component of the wall-induced upwash at either the source or the field level. Similarly, the streamwise velocity perturbation at the axis due to the walls is obtained from equations that involve the antisymmetric upwash components measured at the source and field levels. Model-induced upwash is then expressed as the difference between the total upwash and the wall-induced upwash.

The Schwarz operators are determined from potential-flow theory, in which it is assumed that the wall-induced flow within the control contour is governed by Laplace's equation. The resulting velocity-transformation equations give the upwash and streamwise perturbations at the axis in terms of integrals of weighted upwash values along the contours. In practical situations, continuous upwash distributions are approximated by sets of upwash measurements at discrete points, the integrals therefore being replaced by sums.

The method was tested in a mathematical simulation of a wind tunnel with simple singularities. In another test, data from an adaptive-wall wind-tunnel experiment were analyzed. The method accurately predicted the wall-induced velocities along the centerline of the theoretical wind tunnel and confirmed that the wall adjustments substantially reduced wall interference.

This work was done by Edward T. Schairer of **Ames Research Center**. *For further information, Circle 27 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 29]. Refer to ARC-11586.



The Upwash Is Measured Along Two Contours; namely, the source level and the field level. The upwash distributions are used to calculate wall-induced flow perturbations along the tunnel axis.

Mathematics and Information Sciences

Hardware, Techniques, and Processes

125 Estimating Wall-Induced Velocities in Wind Tunnels

Life Sciences

Books & Reports

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Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Estimating Crop Yields From Multispectral Reflectance

Progress in developing an economical way of predicting yields is reported.

Three reports describe research on a proposed method for estimating crop yields by combining meteorological data with satellite measurements of reflected radiation to estimate crop-absorbed radiation. The concept, when tested over large areas, could form the basis for evaluating crop conditions and estimating yields over regions where ground observations would be too costly or too difficult.

The research involves the terrestrial measurement and analysis of the multispectral reflectance and the amount of radiation intercepted by corn, soybeans, and wheat grown under several different management systems. In principle, the terrestrial radiation measurements can be correlated with satellite spectral reflectance measurements for use in the crop-yield model.

One of the papers, "Spectral Estimation of Absorbed Photosynthetically Active Radiation in Corn Canopies," discusses methods of incorporating multispectral data into mathematical models for crop conditions and yields. It concludes that the absorbed photosynthetically active radiation (PAR), cumulated through the growing season, is a better indicator of yield than is the cumulated-leaf-area index. It suggests that the absorbed PAR may be estimated from the spectral reflectances of corn canopies with large areas, where direct measurements of leaf-area indices would be prohibitively costly.

Another paper, "Spectral Estimates of Solar Radiation Intercepted by Corn Canopies," describes experiments on combining spectral and meteorological data. Agronomic data collected to coincide with the spectral data included the leaf-area index, biomass, development stage, and final grain yields. The paper concludes that the concept of estimating the intercepted solar radiation from spectral data represents a viable approach for merging spectral and meteorological inputs.

The third paper, "Techniques for Measuring Intercepted and Absorbed PAR in Corn Canopies," describes a study of several techniques in which a line sensor that spatially averages the photosynthetic-photon flux density is used to measure the transmitted and absorbed PAR in corn canopies. The effects of the orientation and length of the sensor upon measurements of the transmitted PAR and the errors induced by using the intercepted PAR (the total incoming radiation minus the transmitted PAR) as an estimate of the absorbed PAR, were examined. The measurements of the intercepted PAR generally resulted in less than a 4-percent overestimate of the absorbed PAR throughout most of the growing season. Thus, the intercepted PAR appears to be a reasonable measure of the absorbed PAR.

This work was done by C. S. T. Daughtry of Purdue University for **Johnson Space Center**. *To obtain copies of the reports, Circle 82 on the TSP Request Card.*
MSC-21060

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Letters

The "Letters" column is designed to encourage a wide exchange of ideas among *NASA Tech Briefs* readers. To contribute a request for information or to respond to such a request, use the feedback cards in this issue, or write or call: Manager/Technology Transfer Division, P.O. Box 8757, Baltimore/Washington International Airport, MD 21240; (301) 859-5300. While we can print only a small number of letters, we will endeavor to select those that are of varied and wide interest.

FREE PUBLICITY

I have developed a VDT, CRT radiation antiglare product. Also a new printer silencer. Your polymer articles and acoustical pieces have helped my product R & D immensely, and your polymer rust VV effect articles, also. What is the procedure for publicity in Spinoffs? *I can send R & D reports at your request. Absolutely wonderful articles. Thank you!*

Christopher B. Veleke
President
Data Research
Portland, OR

To find out if you qualify for publication in *Spinoff*, NASA's annual report on commercial applications of NASA-developed technology, contact Linda Watts at NASA Spinoff, Technology Transfer Division, P.O. Box 8757, BWI Airport, MD 21240.

ECHOES OF THE ECO-SPHERE

My first issue—it looks great! Where can I get a reprint of the EcoSphere technology transfer?

D.B. Jensen
Cons. Engineer
Realtime Consulting
Mansfield, OH

Engineering Research Associates, Inc., 500 N. Tucson Blvd., Tucson, AZ 85716 (602/881-6555) is the exclusive licensee of the EcoSphere technology, which was developed and patented at NASA's Jet Propulsion Lab. For more information, contact ERA, Inc., in Tucson, or the Patent Counsel at JPL. His name and address are on page 29.

WITH THE NAVY

I was especially intrigued by the Oil-Free Compressor (NTB, p. 130, March/April 1986). This would solve a major shipboard problem which occurs with maddening frequency in heavy seas. No compressor was ever designed for shipboard use, regardless of what is written. The oil-free compressor should be standard gear on Navy ships. I intend to investigate this problem further. Tech Briefs has helped.

Christopher P. Sagovac
Lt. J9
U.S. Navy
FPO San Francisco, CA

NASA Tech Briefs is a very informative publication. You are doing a great job of providing information on what your labs and consultants are doing. I wish your concept of providing this type of information could be expanded to other government agencies. I work for the Air Force at Hill AFB, Utah, doing electronic failure analysis. I feel isolated from other government labs doing similar work, with the exception of the information I receive through Tech Briefs.

Scott M. Edwards
Ogden, UT

The U.S. Navy publishes a free monthly technology transfer fact sheet. For more information about becoming a subscriber, write: The Navy Domestic Technology Transfer Fact Sheet, Code E211, Naval Surface Weapons Center, Dahlgren, VA 22448-5000.

WITH THE SCOUTS

Would it be at all possible to obtain copies of the report of the National Commission on Space and the report of the investigation of the shuttle failure for use as background for the Boy Scout Space Exploration Merit Badge?

Neal E. Wilson
Boy Scouts of America
Newington, CT

The report of the National Commission on Space has been published by Bantam Books. It is available for $14.95 plus $1.00 handling from Science News, Book Order Service, 1719 N Street N.W., Washington, DC 20036.

The report by the Presidential Commission on the Shuttle Challenger Accident is on sale for $18 a copy from the Government Printing Office, 710 North Capitol Street, Washington DC 20401. The order number is 040-000-00496-3.

WITH THE WEEDS

The article on NSTL plant-based purification systems (NTB, May/June, p. 18) caught my eye. I would appreciate any additional information available on its application to individual homeowners.

Gerald A. Loignon, Jr.
Assoc. Mgr.—Performance & Results
South Carolina Electric & Gas Co.
Jenkinsville, SC

You can contact NSTL's technology utilization officer for more information on applying plant-based purification technology. His name, address and phone number are listed on page 29.

"FRAMEWORK" FOLLOW-UP

The "Framework for Action" series (May/June 1986, pp. 157-161 and preceding installments) was excellent. It would be nice if reprints were available.

George D. Uffenorde
Senior Specialist Engineer
Boeing Commercial Airplane Co.
Seattle, WA

For information concerning the availability of "Framework for Action" reprints, contact the Office of NASA Productivity Programs, NASA Headquarters, Code ADA, Washington, DC 20546; (202) 453-8437.

Information concerning the 1986 NASA Symposium on Quality and Productivity "Strategies for Revitalizing Maturing Organizations," to be held December 2-3, 1986, in Washington, DC, can also be obtained by contacting the Office of Productivity Programs.

CHANGE OF PLANS

I am writing to comment on a photograph in the July/August issue of NASA Tech Briefs. On pages 12 and 13, you show an aerial view of Kennedy Space Center, including the Vehicle Assembly Building, Launch Control Center, and Orbit Processing Facility. I would like to call attention to the fact that this photograph is reversed.

When viewing the VAB from the south (the side with the American flag and bicentennial emblem), the LCC should be on the right, while the OFP would appear on the left. I have enclosed a copy of the map of the VAB area at KSC, which should clarify this. I hope that this was simply an oversight on the part of your staff and does not mean major facility modifications are being planned here at KSC.

Arlan G. Cage
McDonnell Douglas Astronautics Company
Kennedy Space Center, FL

Clyde Pennington asked us in what mirror we took that photo of the VAB. For the many who wrote or called to tell us the picture was "flopped," don't worry—the bulldozers aren't on the way. We regret the error.

MORE MAILBAG

No direct application yet, but it give me interesting ideas and is a prize publication in my periodicals library. I also think the selected commercial advertisements are a plus over the former (no ads) version.

A couple of page article on COSMIC would be useful in a future edition.

Jeffrey S. Katz
Design and Development Engineer
Advanced Computer Applications
Windsor, CT

Computer Previews '87, a special issue to be sent to all NASA Tech Briefs subscribers in December, will contain articles on COSMIC,® as well as other information on NASA's computer capabilities.

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Mission Accomplished

Through the technology transfer process, many of the systems, methods and products pioneered by NASA are re-applied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.

To the inventor, the challenge faced time and again is to push back the gates of that which is known and enter uncharted territory, to unlock the imagination and discover its secret trails. The trick is to find the key, the muse, the spark of an idea that will burst open the gates, clear the fog, and lead to creative solution.

In February 1986, Joseph King, a 27-year-old engineering associate for RCA's Automated Systems Division, was standing before the gates of the unknown. Working on an intrusion detection system that had already reached the fabrication stage, Mr. King was faced with a problem. The test system, designed to detect simulated targets, was just too large and clumsy.

"In addition to the typical constraints of time and board space, our available power was extremely limited," explained Mr. King. "We had to strive for simplicity."

His goal was to replace the existing circuitry with a new design that would minimize the number of switches on the console and simplify operation of the equipment, consequently bringing down skyrocketing costs. The solution? Experience provided the engineer with a notion where it might be found—in the pages of NASA Tech Briefs.

"I first started receiving NASA Tech Briefs in 1982 while working for Northrop Corporation," Mr. King said. "It's quite a useful and informative magazine. I save all my old copies, never throw one out. If any kind of problem comes up, I have somewhere to turn."

In 1985, his final year at Northrop, Mr. King redesigned a cooling system used to control the temperature of an inertial navigation system. His design was based on a process described in NASA Tech Briefs. "I read in Tech Briefs how scientists working on the Space Shuttle would intentionally frost fluid lines to improve insulation," stated Mr. King. "This gave me an idea. I found that by pre-cooling, by letting the lines frost, we could get down to the temperature we wanted in one hour, halving the amount of time it took to reach the desired temperature."

But for Joseph King this was only the beginning, a warmup exercise. In February 1986, when his test system became a big and growing headache, Mr. King sought out his muse.

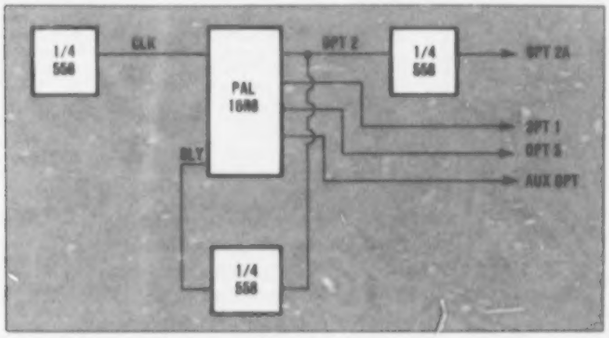
"With thoughts of the circuit in mind, I was looking through an old issue of NASA Tech Briefs (Spring 1984) when I came across the 'Digital Sequence Controller' article," Mr. King recalled. "I said to myself, 'That's just it. That's exactly what we want.' "

This brief, by James O. Lonborg of Caltech, gave the resourceful engineer three ideas. First, the sequencing controller would eliminate several switches on the system's console, simplifying operation. Second, the circuit's power consumption was low enough to allow battery operation, which alleviated Mr. King's power supply concerns. And because of its versatility, the 555 IC described in the brief would provide an ideal initial building block. It could be used as the systems clock, as the various timing elements to provide necessary delays, and, since it could source 200 mA, as the driving stage.

While the sequencing controller would provide many answers, one problem yet remained—lack of space. The chip count required to provide even a single output was well beyond Mr. King's available space. His solution? The invention of the "Multiple Output Sequencing Controller" (see accompanying article), an improvement over Mr. Lonborg's model.

"With the numerous types of PLDs (Pro- ►

RCA Engineers John Carvalho (left) and Joe King.



Block diagram of Joseph King's Multiple Output Sequencing Controller

grammable Logic Devices) on the market," stated Mr. King, "I thought a much more eloquent approach could be taken. After a little more research, I discussed the subject with our local PLD expert, John Carvalho (a senior project member at RCA). Together we decided that by using the concept of finite state machines as applied to MMI's series of PALs and integrated with a network of 555s, a powerful multiple output sequencing controller could result."

Within days the engineers had developed a two-chip version. A tremendous advantage of the design was an over 66% reduction in IC population from the original circuit, resulting in even lower power consumption and, in Mr. King's words, "considerably less real estate." This versatile sequencing controller is now being applied to two other pieces of test equipment in the developmental stage at RCA.

Joseph King has always been a man who gets results. During a term in the Marine Corp (1978-1982) in which he worked on radar jammers, Mr. King established a 95% repair rate, the highest in Marine Corp history. He has no thoughts of resting on his laurels. Currently, he and Mr. Carvalho are developing a device that will allow power current sensing without introducing a power loss into the system. Whether or not the final product succeeds, Mr. King is already ahead of the game, because the next time he walks up that winding path and approaches the gates of uncertainty, he carries with him an invaluable secret: He knows just where the key may be hidden. □

MULTIPLE OUTPUT SEQUENCING CONTROLLER

by Joseph D. King
RCA Automated Systems Division
Burlington, MA 01803

A new multiple output sequencing controller has been designed with only two integrated circuits and a total current consumption of less than 50 mA (see Fig. 1). It operates as an eight-state, gray-encoded machine utilizing combinatorial and registered logic as implemented in a programmable logic device (see Fig. 2).

This new circuit generates clock pulses capable of controlling sequential devices by using a 558 to supply both a system clock and the various timing elements to a PAL 16R6. The two-chip design, made possible by applying the concept of finite state machines, provides several distinct advantages. First, it allows for a variable output pulse width that is not only independent of the system clock, but is also independent of the other additional output pulses. The pulse width is varied by keeping an output high or low for more than one state through the Boolean expressions that define the different states (see Figs. 2 and 3).

A second advantage of this new circuit design is a clocked output that is available only during one or more of the delay stages. The outp t frequency is a user variable, independent of the ►

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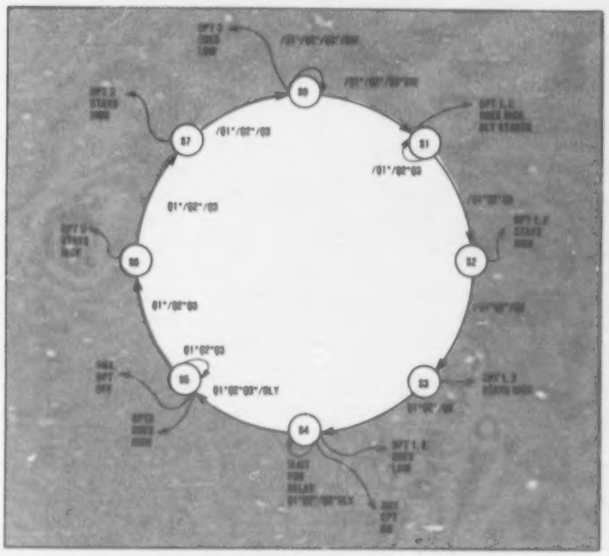
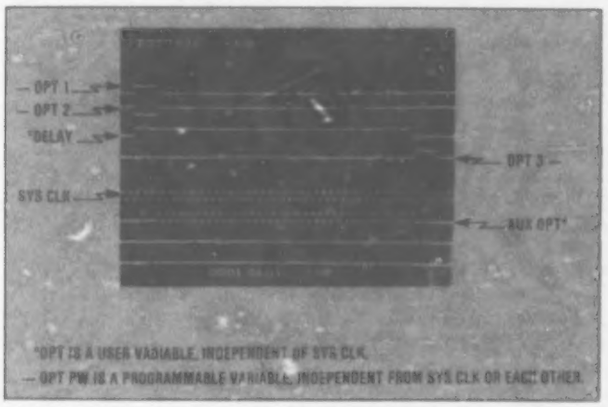
system clock. A possible application of this output is to drive a step motor that supports a video camera. The conventional output pulses could then be used to trigger the camera at each static position.

A third advantage is that the sequencing controller is nonretriggerable, which is achieved by not including the enable switch in the Boolean expression for states 1 through 7. The controller operates in the non-stable mode, requiring a manual switch actuation to start operating the system. Upon completion of the sequencing period, the controller returns to the idle state and awaits retriggering. In a later application, the state equations were modified to allow the machine to free-run until reset. □



Multiple Output Sequencing Controller state diagram


OPT 1
OPT 2
*DELAY
SYS CLK
OPT 3
AUX OPT*
*OPT IS A USER VARIABLE, INDEPENDENT OF SYS CLK.
— OPT PW IS A PROGRAMMABLE VARIABLE, INDEPENDENT FROM SYS CLK OR EACH OTHER.

Multiple Output Sequencing Controller timing diagram

This device generates the control signals for the Sequencer. The count sequence is as follows:

Q1	Q2	Q3		
0	0	0	S0	Idle state waits for switch to be pressed
0	0	1	S1	Generates output 1 pulse for t = 3 * 1/1200 Hz
0	1	1	S2	
0	1	0	S3	Waits in this state for end of long delay
1	1	0	S4	Generates output 2 pulse for t = 3 * 1/1200 Hz
1	1	1	S5	
1	0	1	S6	Return to idle state
1	0	0	S7	
0	0	0	S0	

Multiple Output Sequencing Controller count sequence

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This document was prepared under the sponsorship of the National Aeronautics and Space Administration. NASA Tech Briefs is published bi-monthly and is free to engineers in U.S. industry and to other domestic technology transfer agents. It is both a current-awareness medium and a problem-solving tool. Potential products...industrial processes...basic and applied research...shop and lab techniques...computer software...new sources of technical data...concepts...can be found here. The short section on New Product Ideas highlights a few of the potential new products contained in this issue. The remainder of the volume is organized by technical category to help you quickly review new developments in your areas of interest. Finally, a subject index makes each issue a convenient reference file.

Further Information on Innovations—Although some new technology announcements are complete in themselves, most are backed up by Technical Support Packages (TSP's). TSP's are available without charge and may be ordered by simply completing a TSP Request Card, found at the back of this volume. Further information on some innovations is available for a nominal fee from other sources, as indicated. In addition, Technology Utilization Officers at NASA Field Centers will often be able to lend necessary guidance and assistance.

Patent Licenses—Patents have been issued to NASA on some of the inventions described, and patent applications have been submitted on others. Each announcement indicates patent status and availability of patent licenses if applicable.

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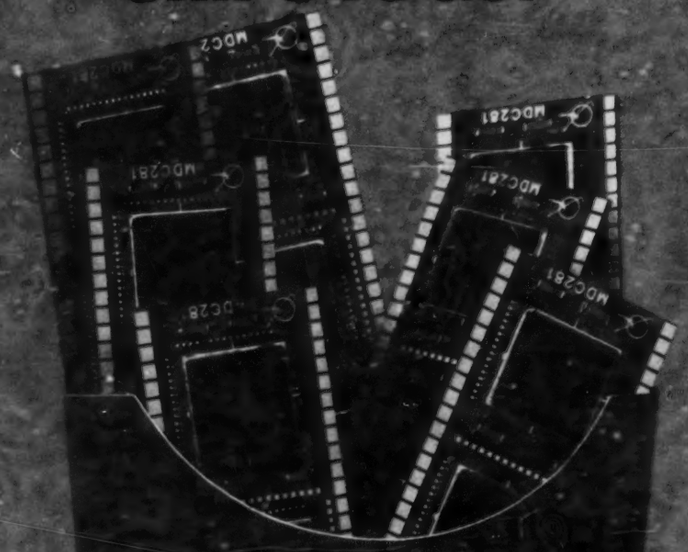

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10/6

1986
Volume 10, Number 6

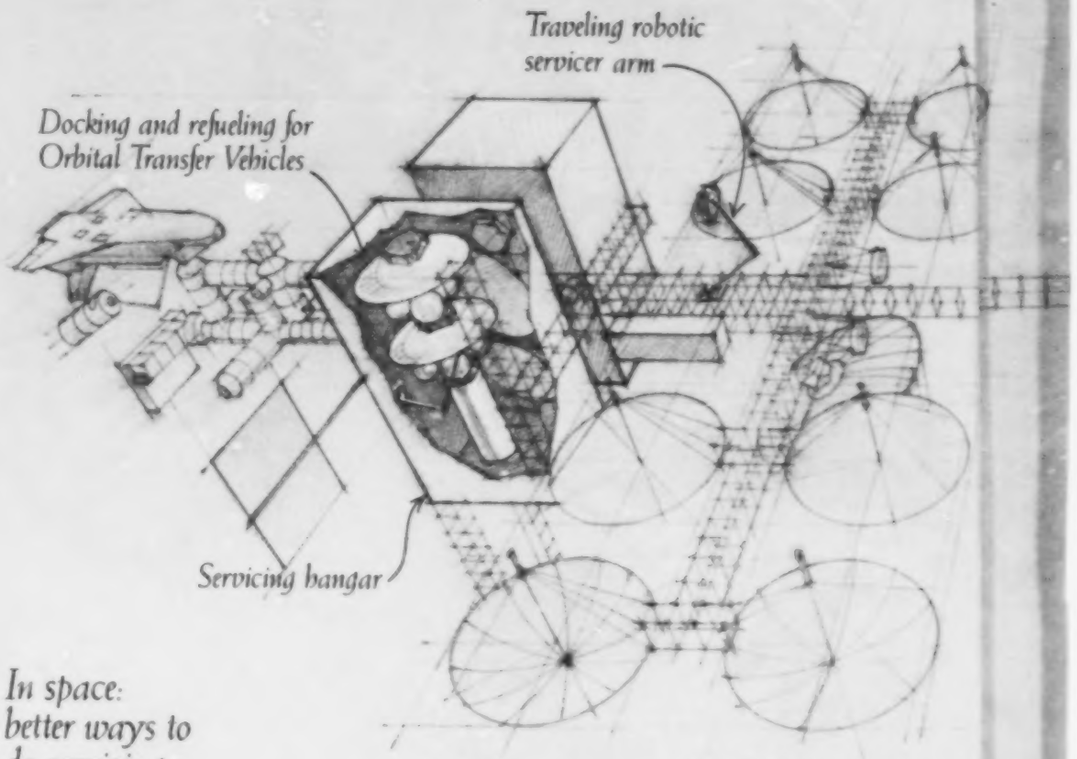
NASA Spinoff Technology:

Using glow discharge techniques to improve sunglasses

NAS1.29/3:

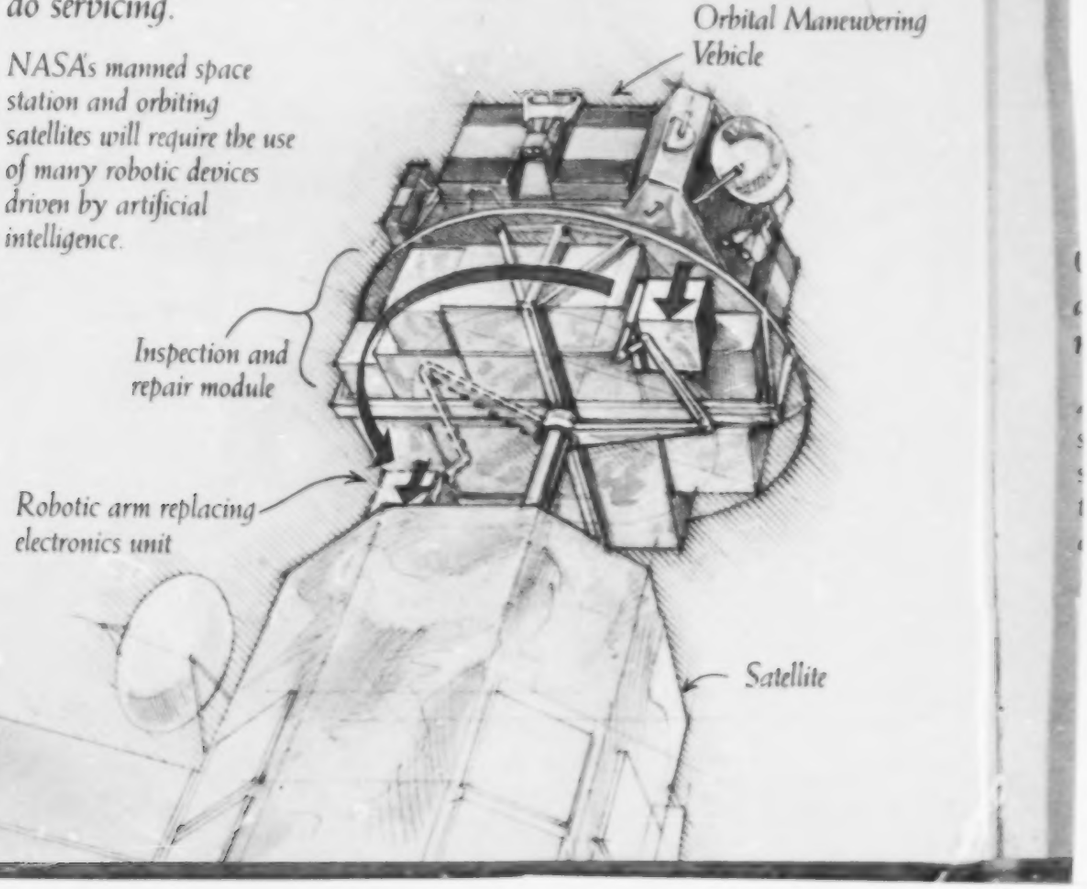
Artificial intelligence and robotics: giving machines the ability to sense, reason and act.

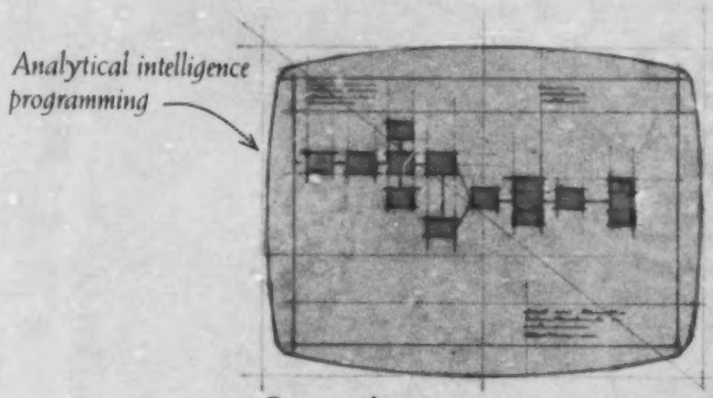
Much as it may hurt to think so, many things might be done better by independently functioning machines than by humans. Certain tasks may require superhuman precision or speed, or need to be done where humans can't go. Martin Marietta is creating systems that combine the ability to sense, reason and take action—to function autonomously and intelligently. And we are exploring ways to put them to work on a variety of tasks.

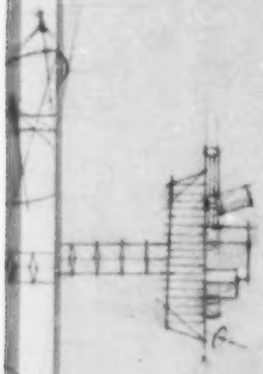


In space: better ways to do servicing.

NASA's manned space station and orbiting satellites will require the use of many robotic devices driven by artificial intelligence.







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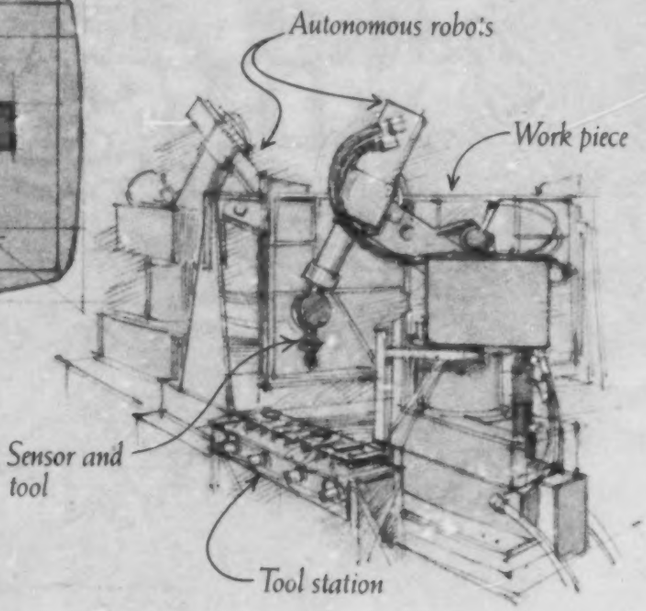

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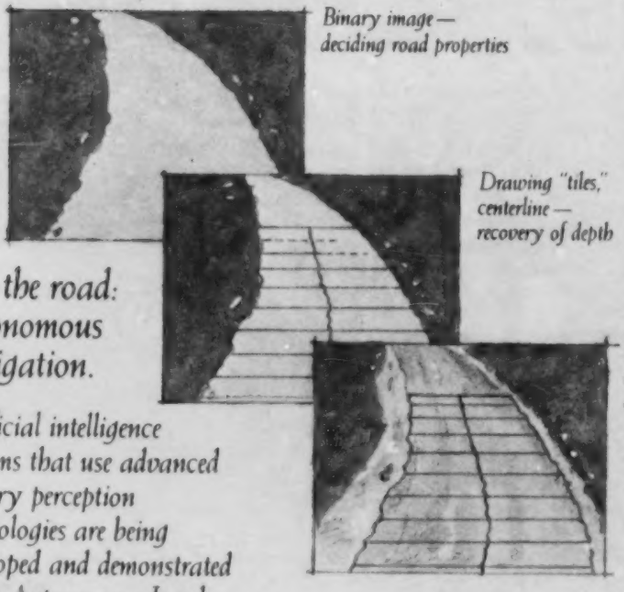
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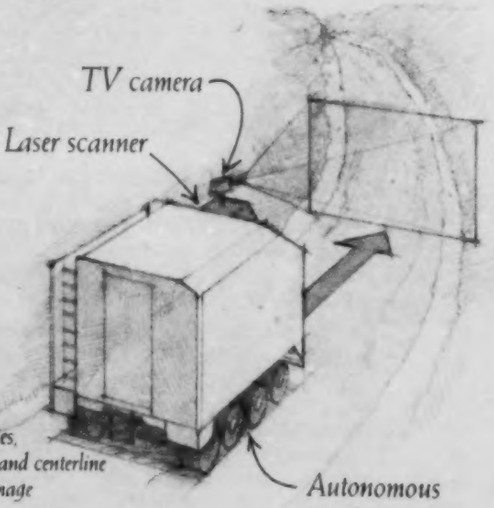

On the road: autonomous navigation.

Artificial intelligence systems that use advanced sensory perception technologies are being developed and demonstrated in the Autonomous Land Vehicle. Already able to follow roads, this mobile test bed will eventually be able to plan its route, avoid obstacles and even thread its way across country.

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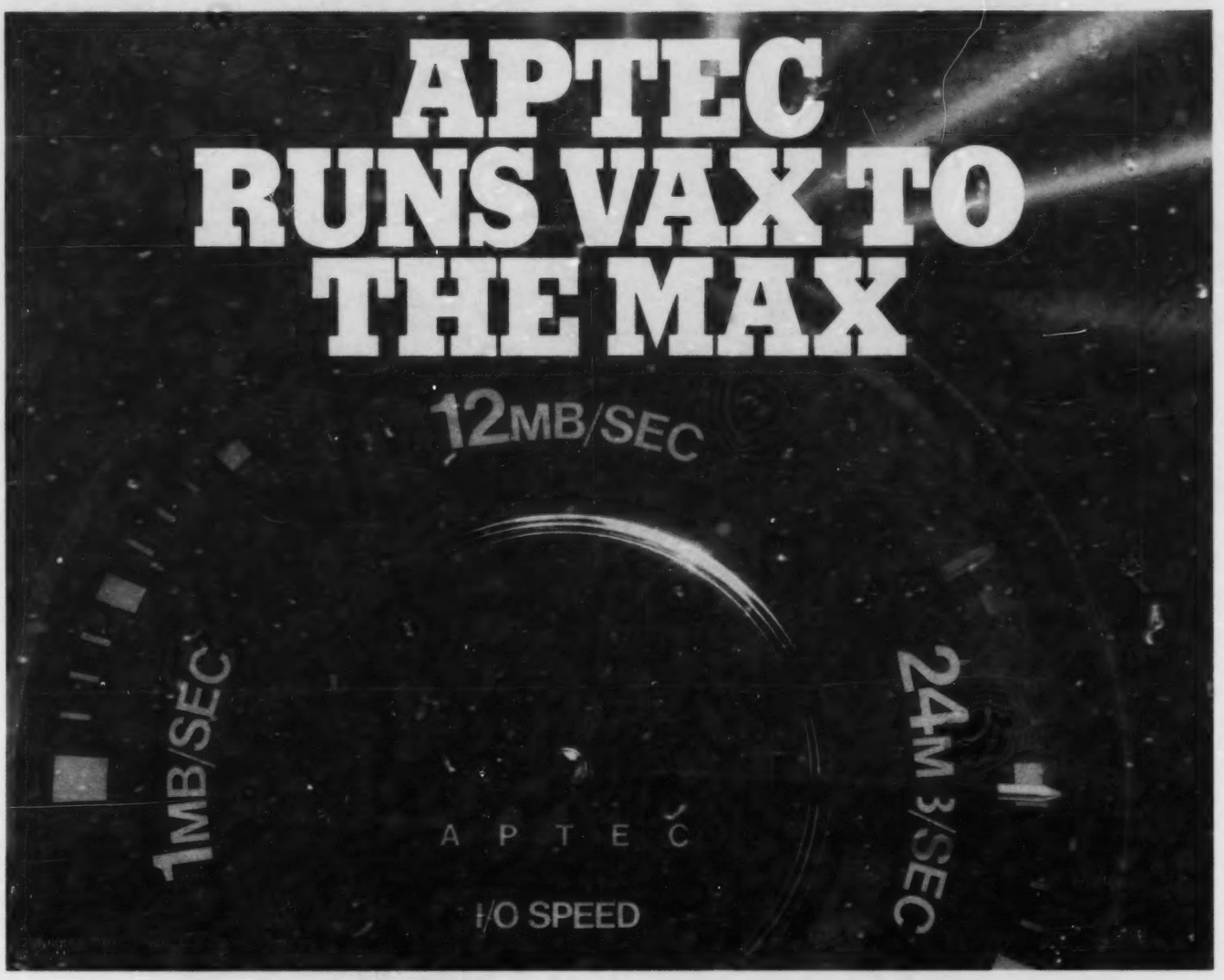

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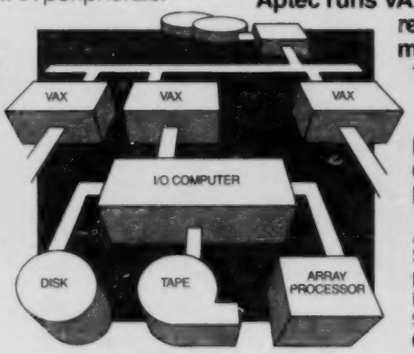

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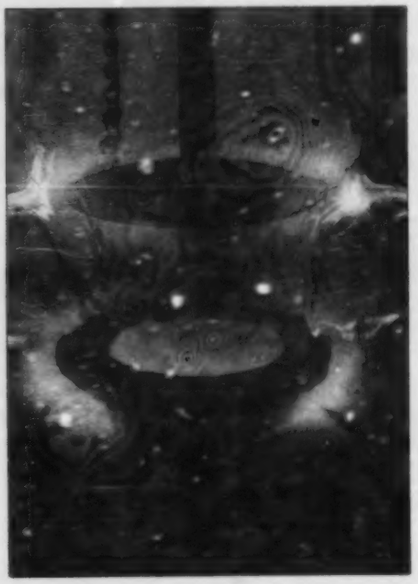

On The Cover: While improving purification filters for spacecraft water reclamation, an Ames research scientist developed a method of depositing a thin plastic coating upon another plastic sheet. This process has since been used on over five million pairs of sunglasses sold by Foster Grant company. See Mission Accomplished, page 99, for details.

This color composite image of Florida from Lake Okeechobee (top center) to Whitewater Bay was taken by a NASA Landsat satellite. Analyzing enhanced photos such as these is one of the services offered by the Technology Application Center, one of NASA's Industrial Application Centers (IAC). A review of the IAC network begins on page 10.

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Thumb Index Technical Section

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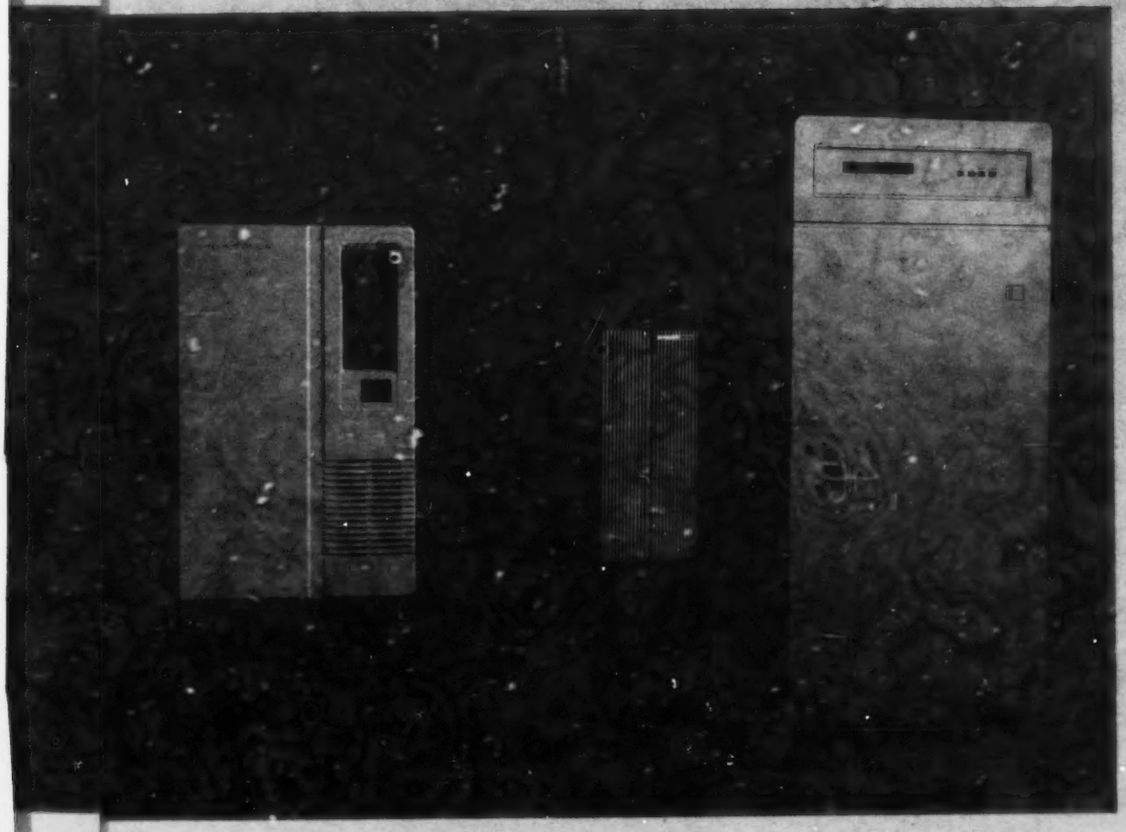

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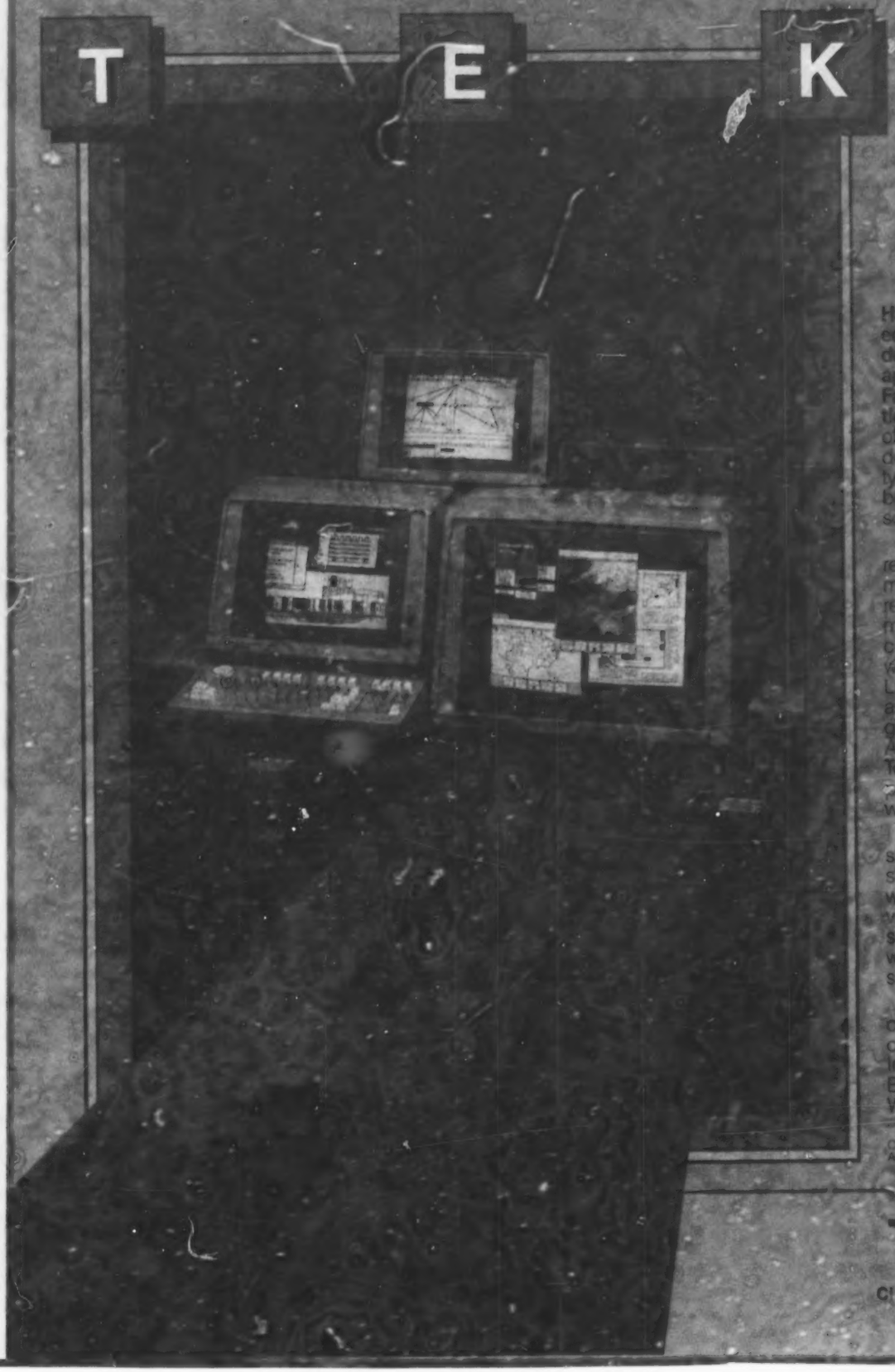

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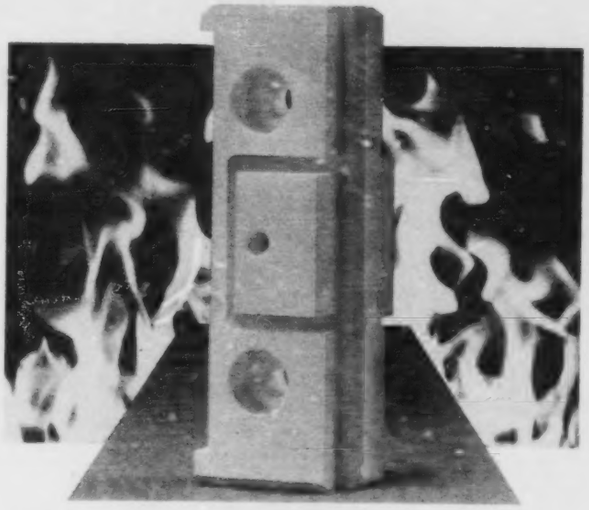

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Editorial Notebook

I was recently delighted to notice that in a single issue of the *New York Times Magazine* NASA-derived technology was credited in two totally different and unrelated stories: the first piece on efforts being made to regain the Americas Cup, and the second on cosmetics testing. We'd known about the Americas Cup effort before through a feedback card, but it is encouraging to see these successful transfers of NASA technology acknowledged in the press.

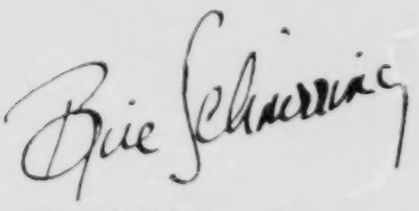
In this issue, we're rashly attempting to describe one of NASA's methods of such technology transfer: the Industrial Applications Centers. I say "rashly" because the organizations themselves have historically had a tough time advertising themselves. We've tried to help out a few with ad copy but, to date, our efforts haven't won any advertising awards, either.

That's one of the reasons we're devoting a feature article to the Industrial Applications Centers. When you offer as wide a range of services as the IACs do, it's close to impossible to describe succinctly what you do, let alone what you are capable of doing. And while they're all part of the technology utilization family, each IAC has a different lineage, with the single common bond being NASA.

As I mentioned to Len Ault, NASA's NTB Publications Manager, the project is a little like trying to dress an elephant. Even with a cooperative elephant, it's hard to get everything on, let alone coordinate the wardrobe.

I don't want to take the analogy so far out that we can't close the loop, but I hope you'll enjoy our tip of the editorial hat to NASA's Industrial Applications Centers; the story begins on page 10. Technology transfer is still in its infancy, more art than science—and these IACS are among the leading alchemists of our time, pushing the envelope of technology transfer.

Doing our bit to transfer vital information, we'd like to point out that the 1981 NASA Tech Brief Index is now available from NASA for ten dollars; send in the coupon on page 97. The index to 1982 will be ready in early January, and succeeding years through 1986 will follow about every two months. □



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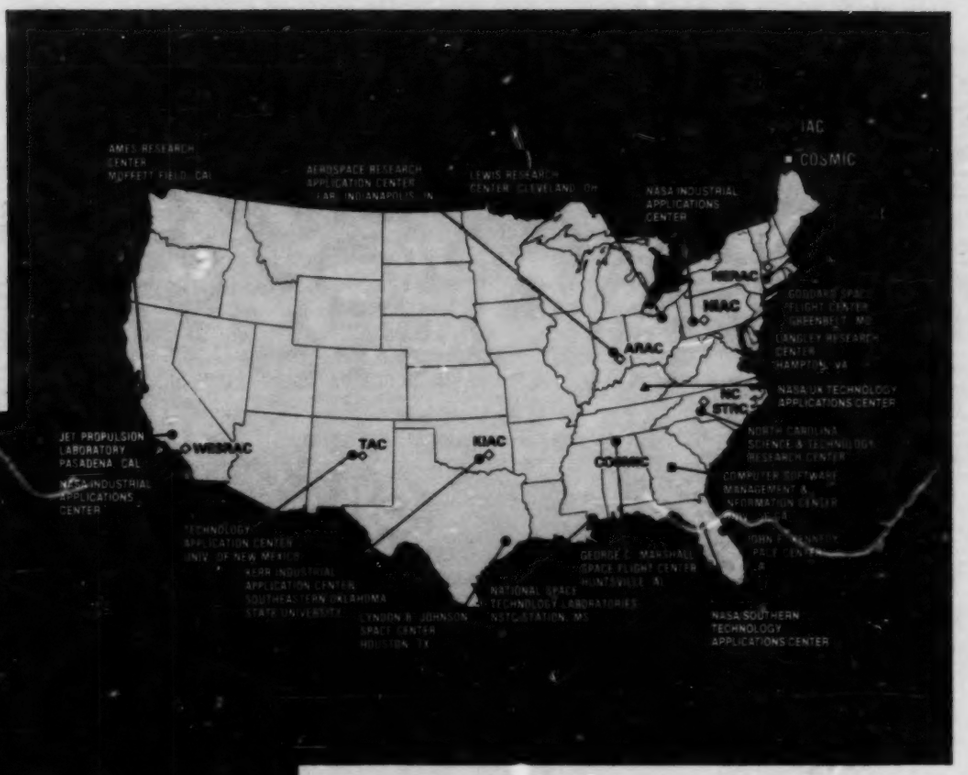
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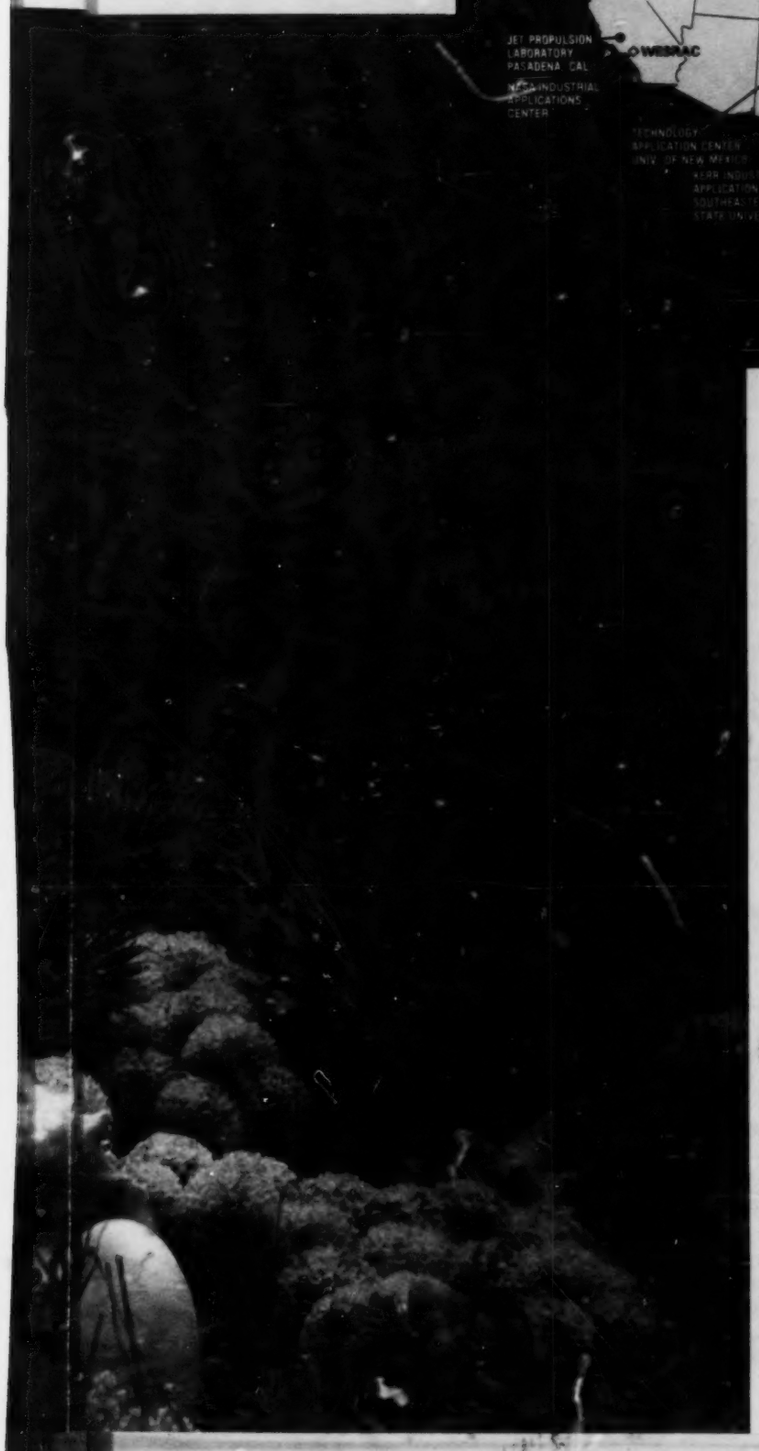


(Photo courtesy The Walt Disney Company, 1986)

Credit Congress with foreseeing down-to-earth applicability in the technological and scientific innovations that NASA and its contractors would create as they led the push into the last frontier; written right into NASA's founding charter is the mandate to spread new technologies throughout the American economy. From its inception, NASA rose to meet this challenge, organizing what today has evolved into the Technology Utilization Division of the Office of Commercial Programs.

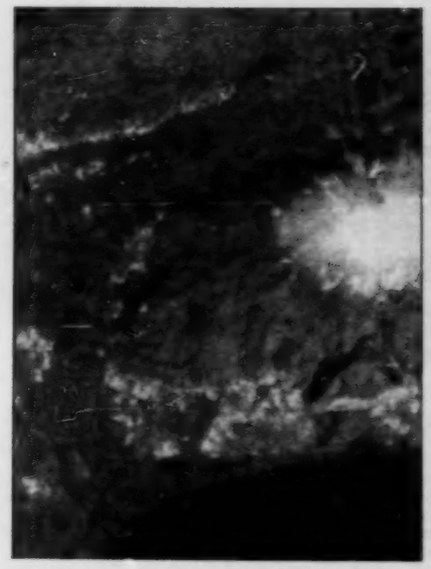
In the scant 28 years since NASA was born, thousands of aerospace-based technologies have been spun off into the country's private and public sectors through this technology transfer network, leading to breakthroughs in business and industry. The network has several components, including one you're holding right now —*NASA Tech Briefs*. Although each part has its function, the Industrial Applications Centers—perhaps the least known, least publicized members of the team—are an underutilized resource representing a wealth of opportunities.

The nine IACs, as they are acronymically known, exist to help American industry sharpen its leading edge by providing access to a vast computerized storehouse of technical knowledge. Located at academic institutions around the country, their ability to draw on millions of documents and more than 400 databases worldwide is important in itself. But the real value-added services offered by the IACs go beyond information retrieval to specific problem-solving assistance and regular contact with laboratory R&D scientists employed by NASA, ►

On the left is a scene from the Submarine Voyage through Disneyland's underwater lagoon. Because the chlorine in the water degrades their paint, the figures have to be removed, cleaned, spray painted and repositioned every three months. The NASA Industrial Applications Center at the University of Southern California came up with a photopolymer originally designed to protect lenses in space. Coating the figures with the polymer should reduce the maintenance by a factor of three. The map shows NASA's Industrial Application and Field Centers.

other government agencies, and universities.

Because typical IAC funding comes from multiple sources—NASA, the sponsoring institution, state subsidies and IAC users—the centers are able to provide their services at remarkably modest fees. They provide free estimates, often based on a verbal statement of a client's needs. And because the IACs' very reason for being is to share NASA-developed technologies, personnel actively welcome inquiring minds; the matter doesn't have to be highly technical—they're interested in answering questions and finding solutions to even the most earthbound problems.



To the left is a false color composite image of a coastal area of Iceland composed of three channels from Landsat multispectral scanner satellite data. Near the middle of the photo is a snowcapped mountain encircled by a river valley that runs into the sea. The photo to the right is a computer classification of the same image. Each color relates to a cover type identified by the computer. Both photos are typical of the services performed by the Technology Applications Center at the University of New Mexico.

The Big Search

While each Industrial Application Center has a particular forte, the basic assistance pattern is fairly constant, and all centers have access to tne massive RECON database, where results of all NASA research are stored. A potential client contacts the nearest center, describing a problem or information need. In consultation with an IAC information specialist, details of the problem are specified and the databases appropriate for the search are considered. From the resulting list of relevant titles, authors, organizations, document sources and abstracts, the client can order complete texts of particularly interesting articles; the IAC can also provide the names of prominent researchers doing work in the subject area.

Several types of search services are available, depending on the client's needs. One highly effective method, the **Interactive Search**, requires a personal visit to the IAC. While a database specialist reviews databases on line, the client can watch search progress on his own terminal. This method integrates the skills of the IAC's database expert with the client's own detailed knowledge of his problems and interests. The **Remote Interactive Search** obtains the same results from any location; all that's needed is a personal computer, telephone, modem, and two phone lines. The p.c. is linked to the IAC's search station through one line, and the client is linked to the database expert on the second. In a **Selected Search** (following a standard one), an IAC staff member who's expert in the given field reviews preliminary reports and selects the most germane material. If necessary, an expert from the university associated with the center can be tapped for assistance. Finally, the **Current Awareness Search** can track specific technologies on as many databases as necessary, with updates on the available literature issued to the client on his chosen schedule.

An Inside Look

Though every Industrial Application Center works at technology transfer, each has unique characteristics.

The Aerospace Research Applications Center (ARAC), associated with the Indianapolis Center for Advanced Research, Inc., was the original IAC, developed in 1963. As director F. Timothy Janis explains, ARAC emphasizes an engineering approach to problem solving. "Our purpose is not only to look at transferring technology to the private sector; because there is probably a solution to your problem, we ought to be able to arrive at that solution through adaptive engineering, be it analytical or be it real."

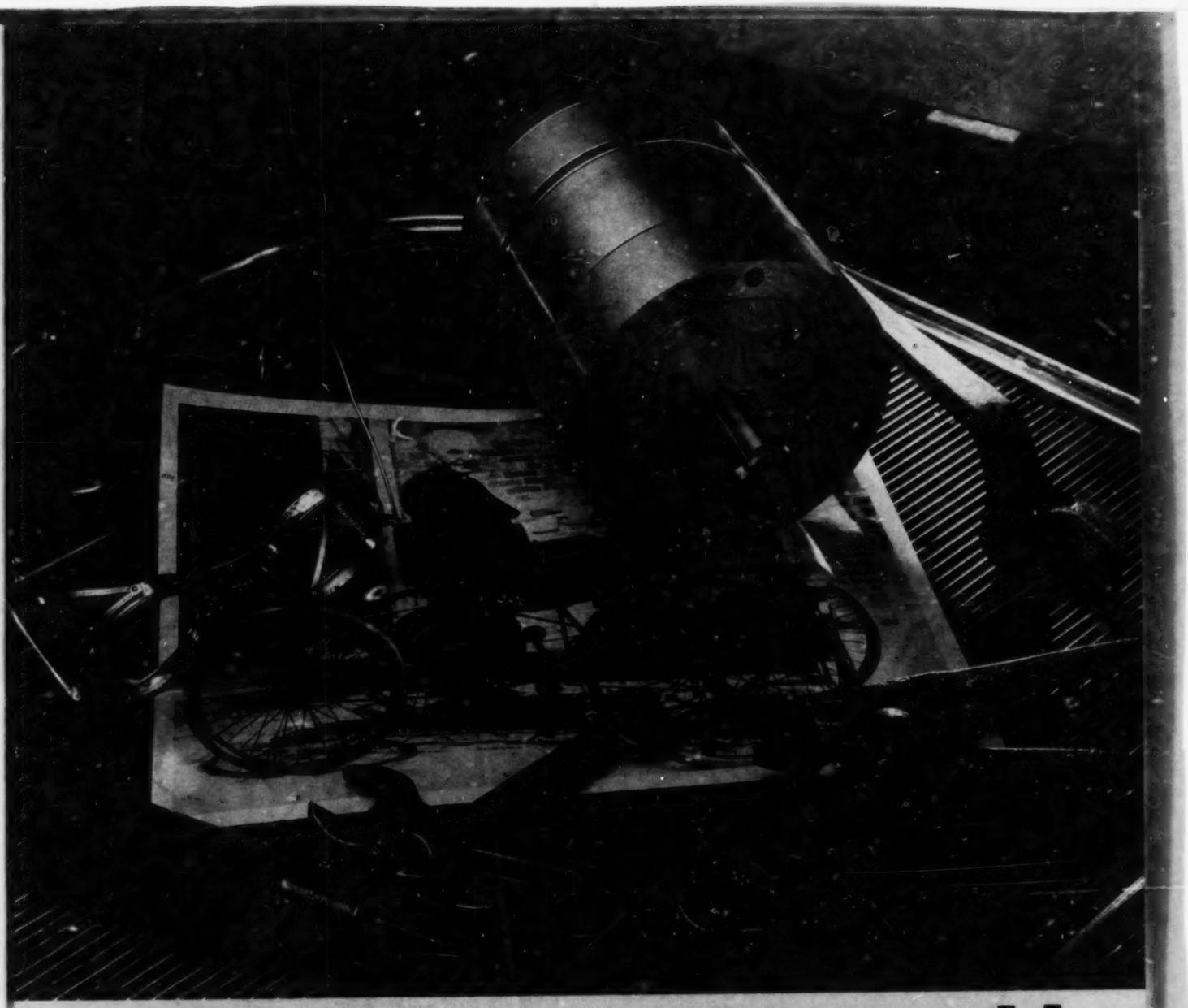
ARAC, with 14 engineers on staff, specializes in value-added engineering studies for its clients. Each client first states the problem to a sales representative. When the problem is well defined, a project engineer is assigned to the case and sets several relatively independent processes in motion:

- A traditional search is made of the appropriate database(s).
- Simultaneously, the engineer defines the problem for one or more of the 600 technical experts associated with the center.
- A problem statement is sent to the three technology counselors employed by ARAC, who are based at Marshall Space Flight Center in Alabama, the Department of Energy's Argonne Laboratories, and the Department of Defense's Naval Research Laboratory. The counselors contact the appropriate people at their locations, and relay information and suggestions back to the project engineer at ARAC.

The project engineer is responsible for integrating all of the resulting information, whether derived from the searches or from expert reports. Contact with participating experts follows, and the engineer uses what he has learned to present a number of possible solutions to the client. The engineer's objective is not to do the client's design work, but rather to make recommendations based on information gathered and professional judgment. Follow-up assessments are made to assure product quality and to ascertain utility.

The decision to locate the **NASA Industrial Applications Center (NIAC)** at the University of Pittsburgh was originally based on the school's library science emphasis, now generally called "Library Information and Systems," and its concept of information as a distinct product.

The Pittsburgh, PA center has a strong orientation toward business and industry. Paul A. McWilliams, NIAC's executive director, explains one center specialty: "We help companies find new or emerging technologies that will help them regain their competitive edge in the marketplace. Thus, when buggywhips go out of style, we locate technologies that allow the manufacturer to change the product. We look for a product that ►



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has a stronger potential market, but requires minimum possible investment in retraining of the present workforce. At the same time, we seek sophisticated NASA technologies that can't be reproduced in someone's garage next year, which could force a client out of the marketplace."

NIAC also emphasizes space commercialization and has expertise in custom database construction. The center is currently expanding its technology transfer efforts by developing satellite institutions to assist industry in nearby states. Says McWilliams: "What we have is a mechanism to heighten awareness of NASA technology through the universities and colleges within a state. These institutions have access to the state's business and industry, and know them far better than we could. They'd be able to talk about the problems within an industry or among companies they know well, and then we'd take the next step and recommend how to resolve the problems."

NASA's **Southern Technology Application Center (STAC)** serves the private sector in the Southeast, and puts a special emphasis on researching patent potential for small companies. Headquartered at the University of Florida in Gainesville since 1977, STAC can access more than 1,200 databases containing over 500 million records. Using NASA's RECON database as a starting point, the STAC staff works with clients in the field to insure full utilization of its services, and makes access to experts easy by profiling several thousand in a database.

Recognizing that small, high-tech companies and innovators are often frustrated by the intricate procedures and major expense involved in patent application, STAC offers product potentiality studies to shortcut the process. They search for pertinent existing patents and make "prior art" and "state-of-the-art" assessments. From search results they determine if an idea can be patented. An innovator must still consult an attorney, but much of the work has already been done—and at a fraction of the usual cost.

Founded in 1964, the **Kerr Industrial Applications Center (KIAC)** at Southeastern Oklahoma State University in Durant deals primarily with small businesses. Director Tom McRorey says, "Through the state Department of Economic Development and Small Business Development Center networks, we're able to provide technical assistance to people who don't know what to ask for and can't pay large sums to have it provided. Most of this information can't be obtained anywhere else.

"When you deal with small businesses," he notes, "you deal with every kind of company. We do quite a bit on the oil and gas industry, and work with several small metal fabrication companies. We also do frequent searches in corrosion resistance and heat-resistive coatings."

KIAC caters to larger companies, too. According to McRory, in some companies "the engineering and operational people don't talk to each other very much. So even though a major company might have the capacity to do essentially what we do, and might be doing it, not everyone in the company knows about it. Or it's easier to pay KIAC than it is to go through the bureaucracy."

Associated with the University of Kentucky, the **NASA/UK Technology Applications Center** directs much of its attention toward non-commercial technology transfer. Center director Bill Strong says that "NASA/UK is primarily oriented towards providing science and technological information to the public sector, i.e. local and state governments, as opposed to industry and business. We interact with the Council of State Governments, the Kentucky Municipal League and other public-sector organizations."

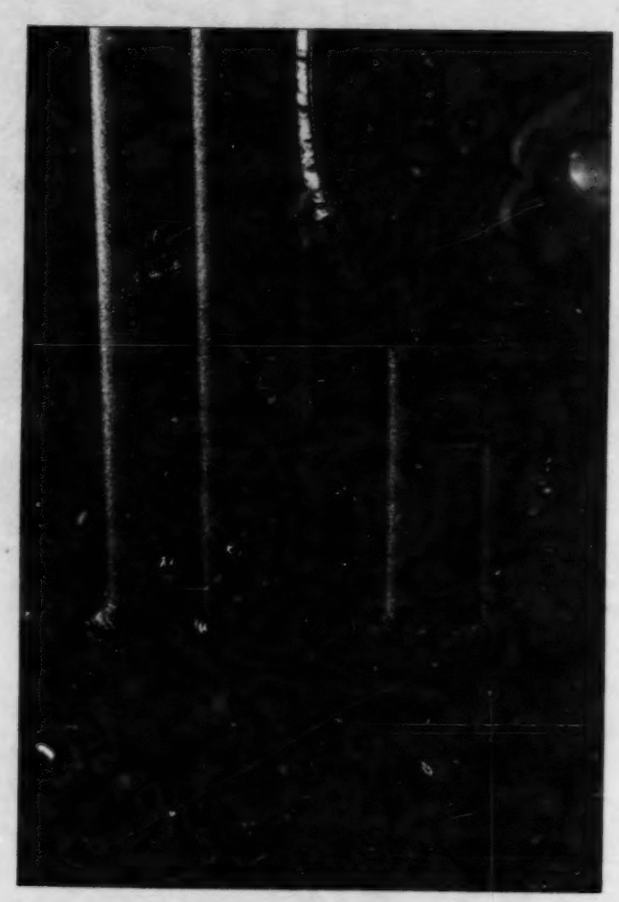
Located in Lexington, the Council performs research studies for the 50 states; since 1977 NASA/UK has been answering its technical questions, which range from economic development to environmental problems and industrial expansion. Says Strong, "Our solutions are applied, not academically oriented. We take academic, scientific and technical results and solve day-to-day problems that confront a mayor. If he's got water pollution or asbestos in his water purification plant, we'll find a solution."

The **IAC at the University of Southern California (WESRAC)** was one of the first centers to emphasize use of Remote Interactive Search Systems (RISS), which the staff sees as highly beneficial to clients. Says Herb Asbury, manager of program development, "Very often the first definition of a question is not vividly painted. When you get the clients on line, the real questions start to come into focus."

He adds, "WESRAC is hooking up with and assisting Small Business Assistance Centers in a number of states. They'll become what we're calling 'NASA Satellite Technical Information Centers,' and will act as remote marketing agents. We'll provide the search services." Asbury expects the "satellites," already in the works in Colorado, Washington, Iowa, Nebraska and Idaho, to be able to generate more demand for their services in their home states.

The **Technology Application Center (TAC)** at the University of New Mexico, in gear since 1963, specializes in remote sensing analysis for natural resources. "We focus on imaging technology for natural resources, the processing and manipulation of multiple channel digital data," says Mike Inglis, the center's associate director.

Much of the information TAC analyzes comes via satellite, commonly the Landsat series, which generates data extending across a wide spectral range. TAC specialists ►



The North Carolina Science and Technology Research Center was asked to recommend a way to decrease metal fatigue in fabric looms. The IAC came up with a process that involves shot peening to introduce a residual compressive stress in the metal making up the looms. The actual shot is shown here. The vertical bars have already been shot peened, hence their silvery appearance as contrasted with the darker horizontal bars.

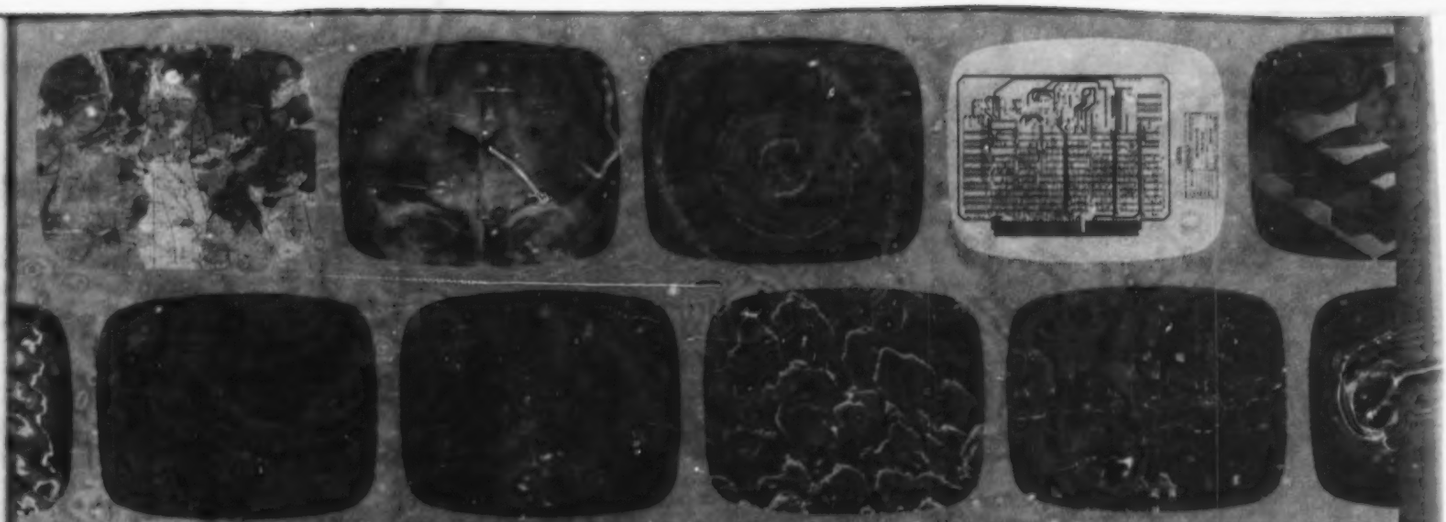


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Illustration of a typical imaging system.

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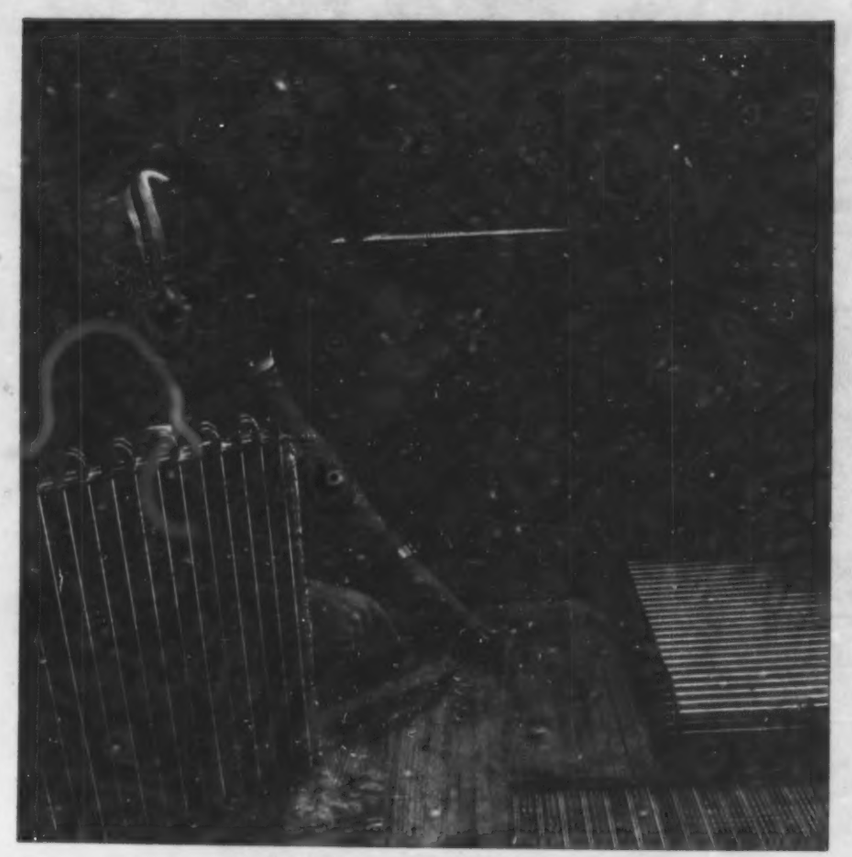


The Dinh Company, Alachua, FL, developed a heat pipe dehumidification system that can double the moisture removal capacity of any air conditioner. NASA's Southern Technology Applications Center assisted with the research necessary to develop the system, whose components are shown here.

process that data using NASA-developed Earth Resources Laboratory Applications Software (ELAS). Results are often used as a basis for on-site follow-up research.

Inglis says, "When a client comes to us with an initial question about remote sensing, we try to introduce him to the value of image-processed digital data and additional remote sensing and image processing applications. We work with him to develop a methodology customized to his needs."

The TAC is also looking at other aspects of imaging technology, especially adaptation of imaging analysis techniques to the field of medicine.

Dan Wilde, director of **NERAC, Inc.**, based in Storrs, CT, likes to think of the center as "50 million solutions waiting for a problem." Clients join for a year, and can call the center whenever they have a problem. Explains Wilde, "It's like a WATS line; when you have it, you use it a lot more than when you have to pay for each call. Our users pay for a year's service, enabling all the people in their company to contact us. This is important, because the more a company uses us, the greater chance they'll have of asking us a question we can really help them with." NERAC's own computer is available anytime a user has a problem, and the center can access any number of databases in hopes of finding the best solution.

"It's hard for us to predict in advance what questions we can answer," says Wilde. "So we say to people, 'For a year you can ask us anything. We'll do our best to help you. If we succeed, great. Come back and ask us another question. If we fail, we're sorry. But come back and try again.'

"It's the companies that keep coming back that get the best help," Wilde notes. He says it's not difficult for a company to save the typical NERAC subscription fee of $5,100, and adds that some subscribers use the center at a volume of $200,000 per year.

"If you've got a problem, all you do is pick up the phone and call your contact at NERAC. Your contact will help you define your problem. Once that is done, you go back to work and your contact goes to work for you. You don't have to know anything at all about computers or databases."

The North Carolina Science and Technology Research Center (NC/STRC), located in Research Triangle Park, serves textile and furniture manufacturers as well as other local industries. Says J. Graves Vann, Jr., the center's acting director, "We go to extra lengths in consulting with our clients to understand and assist them in the precise definition of their problem or question."

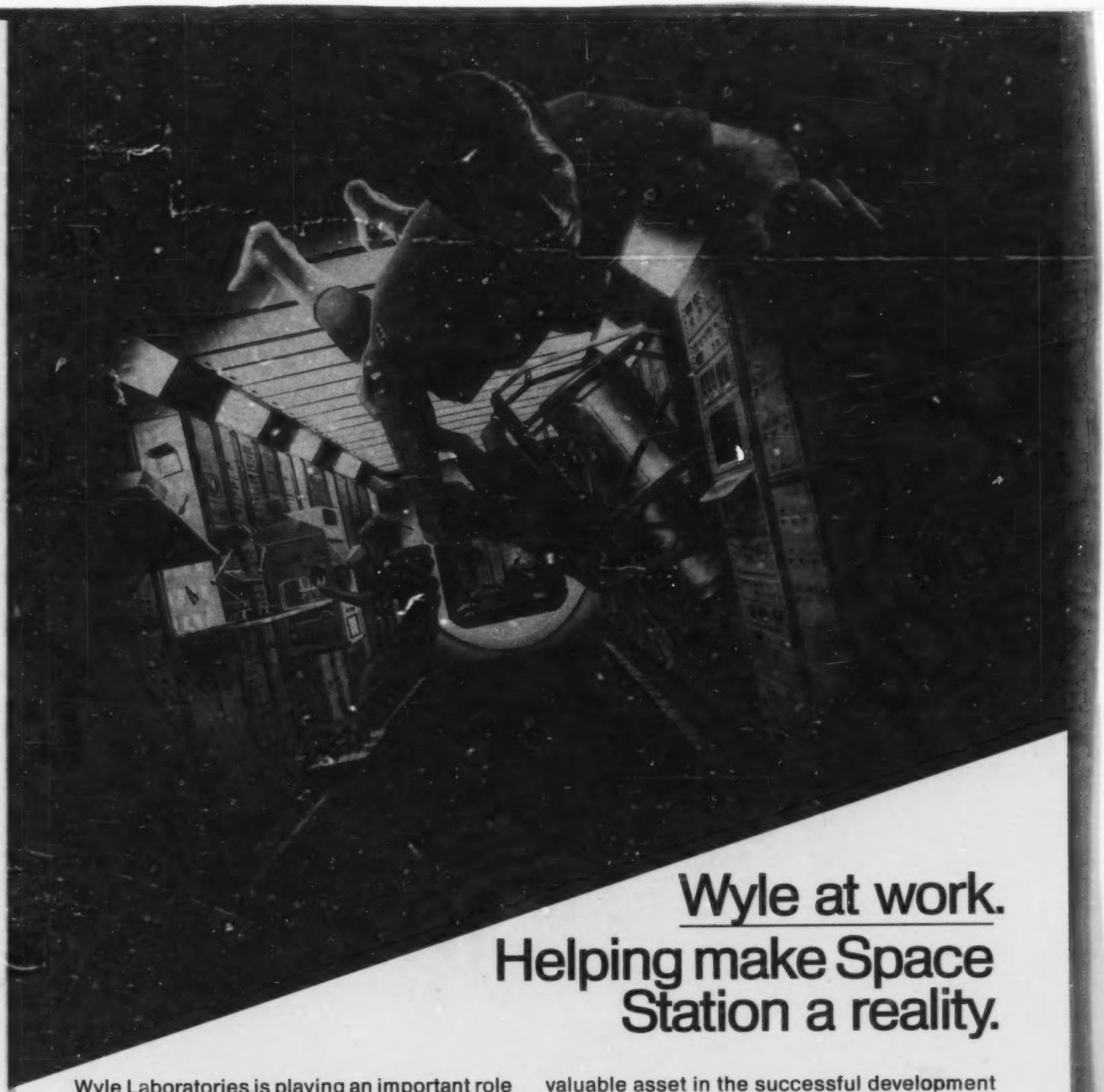
There are several reasons for the close consultation, according to Vann. "It enables us to formulate an overall strategy to identify the appropriate resources to bear on the problem, and it allows us to custom-fit the services to economically meet the client's specific needs." Both the state government of North Carolina and NASA provide support for this center, keeping research costs low.

The **Technology Application Team (TAT)**, located near NC/STRC in the Research Triangle, plays a very specific role within the technology transfer network. Says TAT director Doris Rouse, "Rather than disseminate information from databases, we act as a matchmaker between industry's needs and the NASA technology that can provide the answers. We work with national industry associations to identify the industry's needs. We then consult with the Technical Utilization Officers to find the matching NASA technology. The TUOs also help us locate the NASA people who will work side by side with industry representatives." Additionally, the TAT works with other federal agencies to obtain resources for technology transfer projects. "It takes resources to do the necessary adaptive engineering," explains Rouse. "NASA doesn't have all the money to do that, and usually industry doesn't either. What we do is go to another federal agency that has an interest in that area, for example to DOD. We obtain their cofunding and technical expertise in the project."

• • •

With high-tech experts involving themselves in industrial problems as ordinary (and as crucial) as developing a new product line that won't be obsolete next year, the IACs should have clients beating down their doors. Through their phenomenal information access and farflung network of contacts in government, research and academia, the IACs can easily, effectively and inexpensively answer a multitude of technical questions—even about problems that might not seem technical at first glance. Because it's their specialty, the IACs can often provide more economical problem solving than a company's own in-house computer operations. They not only have the data on hand, they're trained to ask for it. □

For complete contact information on IACs nationwide, see page 28.



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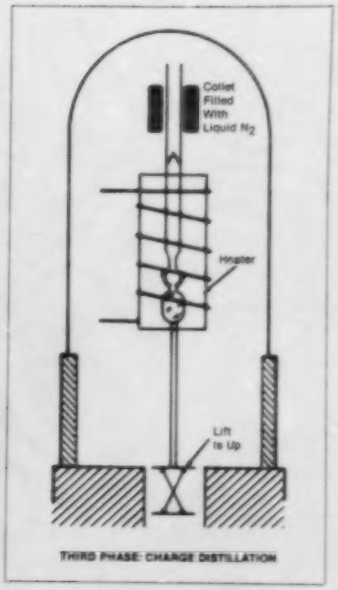
New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 27). NASA's patent-licensing program to encourage commercial development is described on page 27.

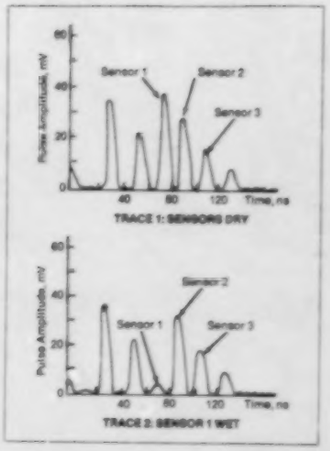


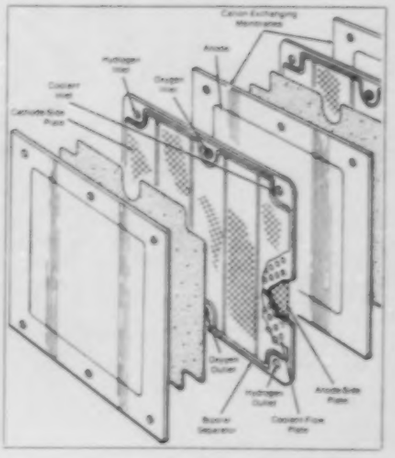
Two-Step Vapor/Liquid/Solid Purification

A vertical distillation system (see figure) combines in a single operation the advantages of multiple zone refining with those of distillation. Developed specifically to load Bridgman-Stockbarger (vertical-solidification) growth ampoules with ultrapure tellurium and cadmium, this system, with suitable modifications, could serve as a material refiner. Because the crystal grows down from the top of the ampoule into the heater until it passes the melting-point isotherm, the bottom end of solid material always has a drop of melt, held by surface tension. There is a segregation of impurities as the molten raw material is distilled to this drop and a second segregation as the material in the drop is solidified. Upon reaching a certain size, the growing drop falls back into the evaporator, carrying with it impurities rejected in the solidification process. (See page 51.)

Laser-Pulse/Fiber-Optic Liquid-Leak Detector

Fluid systems can be monitored quickly for leaks in remote, hazardous, or inaccessible locations by a system of compact, lightweight, fiber-optic leak sensors that are presently undergoing development. The sensors would be installed at such potential leak sites as joints, couplings, and fittings. A sensor is read by sending a laser pulse along the fiber, then noting the presence or relative amplitude of the return pulse (see figure). (The intensity of the reflected laser pulse is determined in part by the index of refraction of the medium surrounding a sensor, through its effect on the electromagnetic modes in the fiber core and cladding.) This leak-monitoring technique should be applicable to a wide range of fluid systems and would minimize human exposure to toxic or dangerous fluids. (See page 38.)

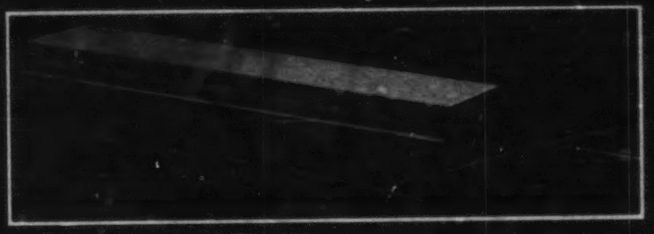




Fuel-Cell Structure Prevents Membrane Drying

A membrane-type fuel-cell battery in which embossed plates direct flows of reactants and coolant has improved reactant flow and heat removal. The compact, lightweight battery can produce high current and power without drying of its membranes. The battery consists of a series of fuel cells (see figure), each of which contains a cation-exchanging membrane between internally cooled bipolar separators. The coolant-path design maintains the anode side of the cell membrane at a lower temperature than that of the cathode side. The resulting temperature differential causes water to diffuse from

BRILLIANT.



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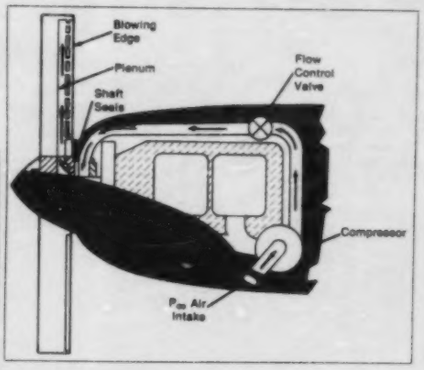
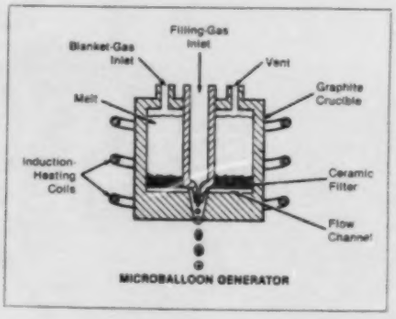
the cathode to the anode, offsetting the opposite transport of water by migrating hydrogen ions (produced by the oxidation of hydrogen) and thereby preventing the drying of the hydrogen side of the membrane. (See page 32.)



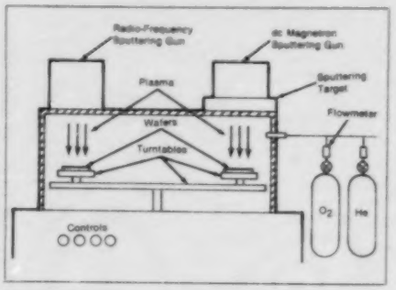
Circulation-Control Variable-Pitch Propeller

A variable-pitch propeller based on the circulation-control airfoil concept has no moving parts other than those needed for propeller rotation. The new propeller (see figure) involves blowing a tangential stream of air from a thin upper-surface slot over the airfoil rounded trailing edge. The jet sheet remains attached to and turns around the trailing edge, thus controlling the circulation around the airfoil. This principle controls the effective pitch of the propeller. With the circulation-control variable-pitch propeller, the effective pitch of the propeller could be varied over a wide range, simply by controlling the flow of air to the blowing slot. In small aircraft, it would improve takeoff performance and increase fuel economy at little or no additional cost. (See page 74.)



Producing Refractory Microballoons

An apparatus produces tiny spherical shells, or microballoons, from refractory metals, ceramics, and glasses. The microballoons are generated at rates of 400 per second or higher with uniform shape and size. The size is selected from a wide range of diameters, ranging from 800 μm to less than 150 μm. The microballoons can be used, for example, in fluidized-bed heat exchangers; as containers for hazardous materials, catalysts in chemical and pharmaceutical processes, and solid fuel for rockets; as fuel containers for fusion power experiments; as shock-wave dampers; and as starting materials for high-strength, low-density sintered alloys and ceramics. (See page 83.)



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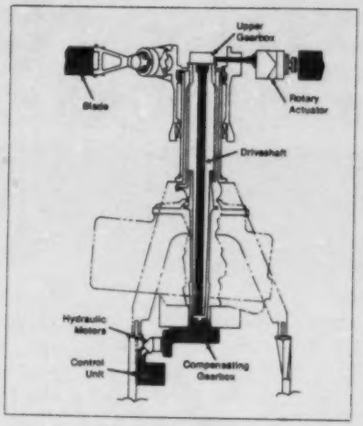
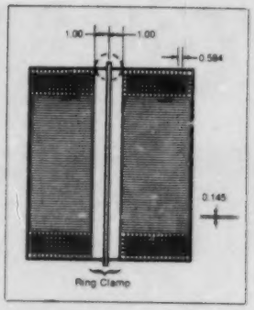
tegrated circuits (IC's) performs four operations ordinarily done in separate equipment: the chamber etches holes, removes photoresist, cleans by sputter etching, and deposits the final layer of metal. Costing less than the separate equipment performing the same functions, the chamber avoids exposing the integrated circuits to room air and, consequently, to oxidation and dust between steps. It also eliminates the time spent in transferring the circuits from one apparatus to the next. The chamber (see figure) contains turntables that continuously turn silicon integrated-circuit wafers to ensure uniform processing of several wafers at a time. Unlike the conventional process, the multifunction process does not use liquid acids and reducing agents for hole etching and photoresist removal. The cost of disposing of these hazardous materials is therefore avoided. (See page 86.)

Pitch Control for Helicopter Rotors

A pitch controller for helicopter rotors uses hub-mounted actuators located symmetrically between rotor blades. The new controller is designed for X-wing



rotors that require collective pitch control; that is, the pitch of all blades must be changed by the same amount. The collective control allows the rotor to be trimmed during a variety of flight regimes, in particular during hovering and fixed-wing flight. The new controller has a short load path and is therefore stiff without excess weight. Its linkage permits large lea /lag motion of the blade without changing the blade pitch; the linkage also restrains vertical shear forces on the blade. Moreover, all linkages and drives are redundant: a single failure cannot cause catastrophic loss of control. (See page 76.)



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Tapered for stiffness and for compact nesting for transportation but nevertheless fabricated with a constant load-bearing cross section, struts made of graphite-fiber-reinforced epoxy resin may be useful in small structures where great strength is not required. Each strut is 9 m long and 0.305 m in diameter at its large end, tapering to 0.025 m in diameter at its small end. A pair of struts is joined by a ring clamp at the large-diameter end (see figure). The end fittings are bonded to the struts during manufacture so that the double-strut assembly can be easily inserted in the truss as a structural member. A completed pair of struts with its fittings has a mass of 5.7 kg. (See page 82.)

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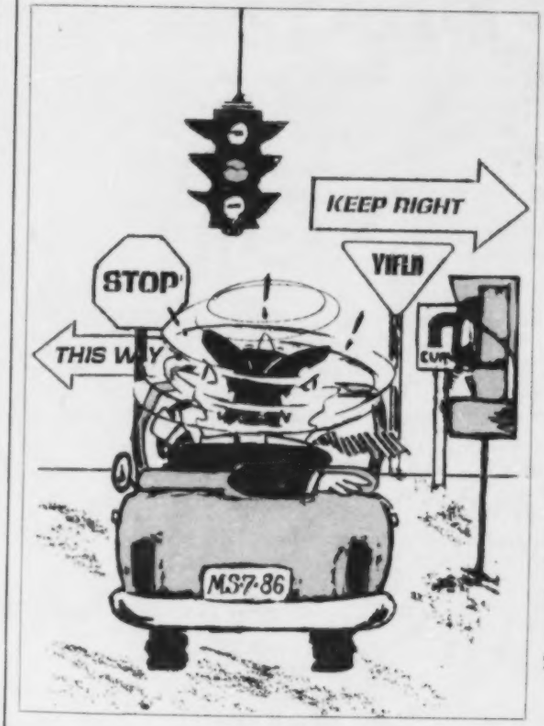

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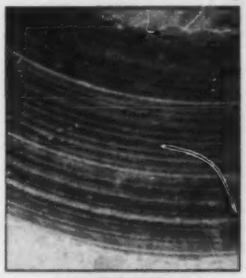
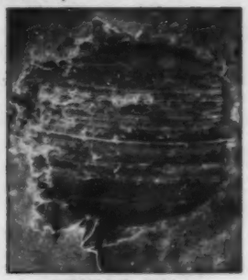


ROTOR BALL



STATOR BALL

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ROTOR BALL

STATOR BALL

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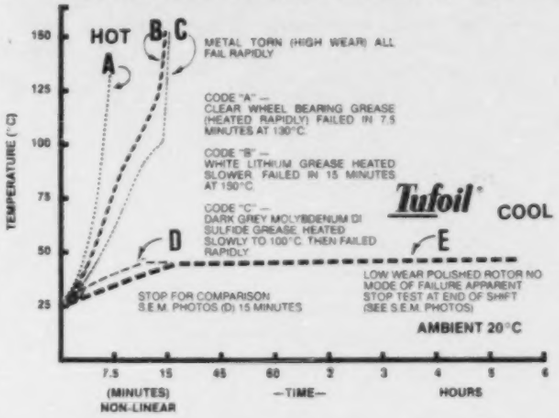
80 KG LOAD — 1700 RPM — .375 DIA. STEEL BALLS



The Tufoil lubricants have been under development for 15 years. They all contain Teflon™ or Fluon™
Teflon is Reg. TM of DuPont. Fluon is Reg. TM of ICI Americas, Inc. TUFOIL is Reg. TM of Fluoramics, Inc., U.S. Patents No. 3,933,565, 4,127,491 and 4,224,173. Other U.S. and International Patents issued and pending.

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TUFOIL LIGHTNING GREASE STAYS COOL AND SHOWS LESS WEAR

Scanning electron microscope photos of the rotor and stator ball scars from "C" (moly disulfide grease) show a great deal of wear and metal distress. "A" and "B" were similar.

The newly developed TUFOIL LIGHTNING GREASE was tested for 15 minutes. The test was stopped at "D" so that S.E.M. photos of the balls could be made for comparison purposes. Both the rotor and stator marks appear polished and smooth. A great deal of super fine PTFE debris (teflon or fluon) can be seen at the bottom of the rotor photos. It is loosely bonded to the metal surface. Solvent rinsing will not easily remove it.

The wear areas on the stator were calculated, showing the spot on the control was 7.7 times larger than for TUFOIL grease (7.7 times the wear). Another test was set up with fresh balls ("E") and run for a full shift of 6 hours. The temperature stabilized at 50°C. The test was terminated with no mode of failure apparent. S.E.M. photos show highly polished surfaces with scar marks only slightly larger than those for "D" (the 15 minute sample).

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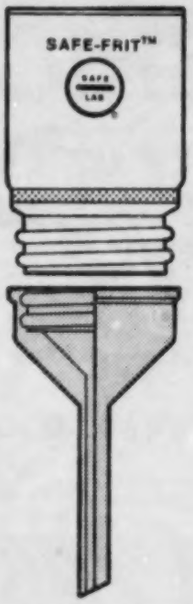

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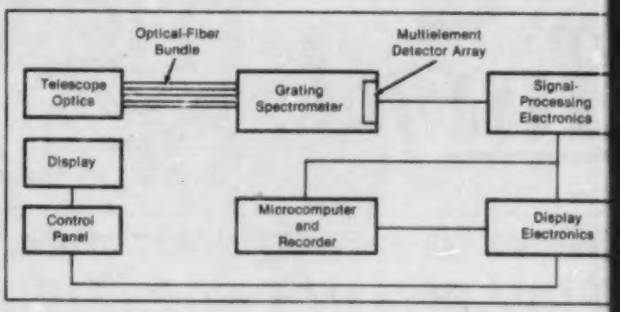

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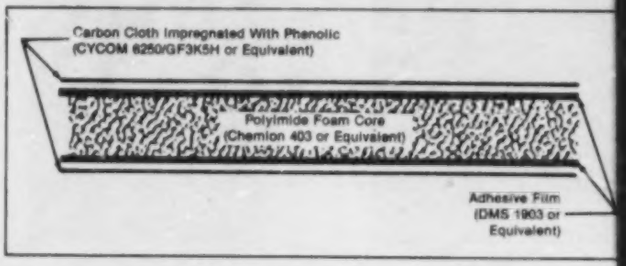
A proposed portable spectrometer for analyzing minerals in the field would generate spectral images like a camera and process the spectral data for real-time identification of materials. To identify an unknown mineral, the user would locate significant peaks in the displayed spectrum and match them to a spectrum in a portfolio of reference spectra. Alternatively, the user would call up a display of prerecorded spectra in the same wavelength region for comparison or allow the spectrometer to determine the best match automatically. In principle, the new instrument would accommodate a wide variety of minerals. (See page 36.)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Fire-Resistant Aircraft Ceilings

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Top Tape Layer Folded Under To Provide Nonsticky Tabs for Ease of Handling

TYPICAL APPLICATION

Strong Adhesive Tape for Cold Environments

An improved tape devised for repairs in space may also find use on Earth in polar regions and in superconducting applications. The tape retains its adherence and strength at extreme temperatures, where conventional tapes would fail. The improved tape (see figure) consists of two layers of Kapton (or equivalent) polyimide tape, which is adequately adhesive at extremely cold temperatures, with a reinforcing layer of thin, open-weave Kevlar (or equivalent) aromatic polyamid. Other mesh materials may also be suitable. (See page 52.)

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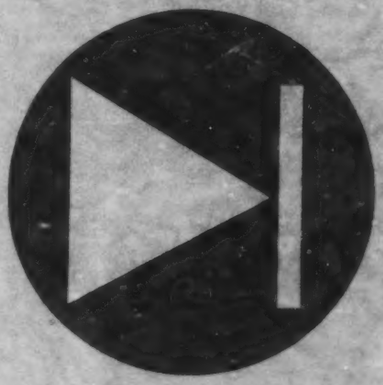
Electronic Components & Circuits



Hardware, Techniques, and Processes

28 Designing dc Inductors With Airgaps
30 Circuit for Lifetime and Surface-Recombination Measurements
32 Fuel-Cell Structure Prevents Membrane Drying
35 Solenoid-Simulation Circuit

Designing dc Inductors With Airgaps

Optimal parameters are obtained by designing near the saturation point.

NASA's Jet Propulsion Laboratory, Pasadena, California

An iterative procedure aids the design of dc inductors with airgaps in the cores (see figure). For a given core area and length, the technique gives a design having the specified inductance and the peak flux density in the core, using the minimum required copper weight. The new technique is superior to the previous trial-and-error technique, which often resulted in cores larger than necessary or in less inductance than could be obtained from a core of given size. Typical applications include lightweight inductors for aircraft electronics.

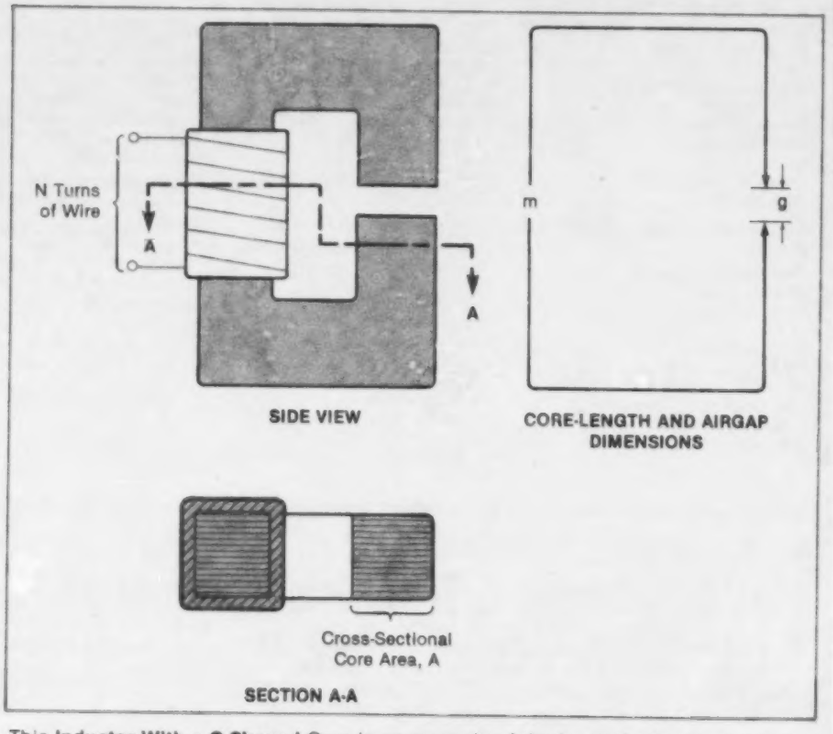
The new approach is based on the full use of the core: The inductor is designed to operate at the saturation flux density of the core material (or at another maximum flux density related to the saturation value). Subject to this constraint, the airgap length, g, and the number of turns, N, are selected to give the required inductance, L. Because there is only one combination of g and N that will satisfy the inductance and saturation criteria for a given core, the procedure quickly leads to an optimal design.

The procedure depends on the fact that N/g is nearly constant, regardless of variations in L, for practical inductor dimensions and core materials. At first, the designer knows the maximum coil current, I; the cross-sectional core area, A; the incremental relative permeability, μ_s, of the core material at the operating point; the maximum flux density, B; the core length, m; and the dc relative permeability, U_s, at the operating point.

The first step is to select a trial airgap, g_1. (Typical gap sizes lie between 0.01 and 0.25 cm.) The designer calculates the initial value, F_1, of the fringing-flux factor, F: This factor depends on g_1 and the other core dimensions. The initial number of turns is then determined from

$$N = \frac{B(g_1 + m/U_s)}{(0.4\pi I)(F_1)}$$

Next, the designer calculates the initial inductance from



This **Inductor With a C-Shaped Core** is an example of the types that can be designed with the iterative procedure.

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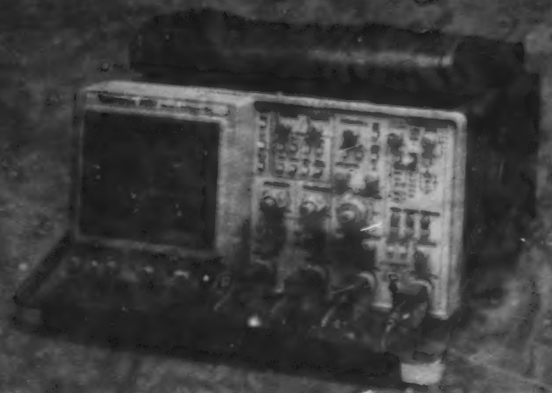

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Circle Reader Action No. 359

$$L_1 = \frac{0.4\pi(N_1)^2(AF_1)}{g_1 + m/\mu_s}$$

If L_1 differs from L by more than the tolerance, then a second airgap length is estimated from $g_2 = g_1 L/L_1$. The preceding sequence of calculations is then repeated to find F_2, N_2, and L_2. These iterations are continued until the computed inductance is sufficiently close to L. Most designs require one to three iterations to bring the inductance within 1 percent of L. The procedure can be executed rapidly on a programmable, hand-held calculator.

This work was done by Albert P. Wagner of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 74 on the TSP Request Card.* *NPO-16739*

Circuit for Lifetime and Surface-Recombination Measurements

A test circuit for silicon solar cells suppresses spurious effects.

NASA's Jet Propulsion Laboratory, Pasadena, California

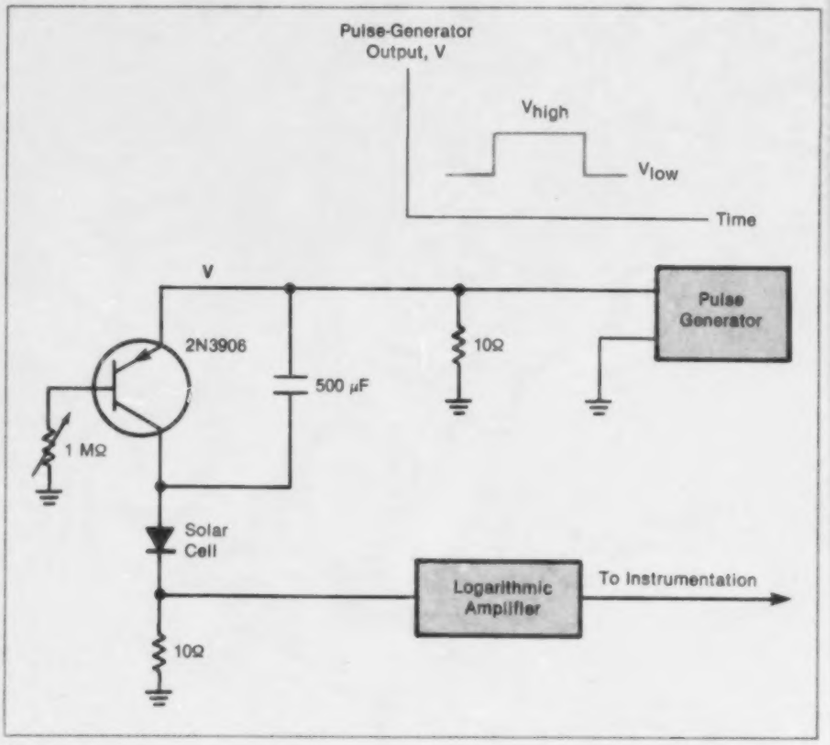
A new circuit increases the accuracy of measurements of the recombination lifetime and the effective surface recombination velocity in a silicon solar cell. Essentially a fast electronic switch, the circuit grounds a forward-biased cell so rapidly that the transient voltage to be measured is not affected significantly.

Previously, the method of open-circuit voltage decay or of junction-current recovery was used. The solar cell was maintained initially under forward voltage and current. Then a reverse current was applied suddenly, and the voltage across the cell was measured as a function of time. For the open-circuit voltage-decay method, the applied reverse voltage was zero; for the junction-current recovery method, the reverse voltage was finite.

In either method, the transient voltage across the solar cell was interpreted by an idealized theory that neglected the effects of mobile holes and electrons in the space-charge region of the cell. This theory is acceptable for germanium devices, which have a low energy gap and a low proportion of mobile holes and electrons. In silicon devices, however, mobile holes and electrons play a prominent role in establishing the voltage transients, and their presence creates errors in the interpretation of the measurements.

The new circuit avoids the problem by placing a short circuit across the solar-cell terminals. The short circuit removes mobile holes and electrons from the space-charge region, within about one nanosecond.

As before, the solar cell is first subjected to forward current. At the designated switching time, a metal-oxide/semiconductor transistor is switched on to create the short circuit (see figure). The recombination lifetime and the time for mobile holes and electrons to cross the base region so that effective recombination can begin is more than 1,000 times greater than the 1-nanosecond discharge time for the space-charge region. Therefore, mobile holes and electrons in the space-charge region have negligible influence on the measurement of the recombination lifetime and surface recombination velocity.



The Switching Transistor initially applies a forward current to the solar cell during the interval when the pulse-generator output is high. At the transition from V_{high} back to V_{low}, the solar-cell anode is effectively shorted to ground within a nanosecond. The cathode-to-ground voltage is measured and recorded as it changes with time.

The short-circuit method is accurate for solar cells in which the diffusion length is about the same as the base thickness and in which the base doping is uniform. This method can still be used for such graded-base devices as the drift-field solar cell or the extended back-surface-field solar cell, provided that the effects of the nonuniform dopant concentration are taken into account.

This work was done by Frederik A. Lindholm, Arnost Neugroschel, and Tae Won Jung of the University of Florida for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 45 on the TSP Request Card.*
NPO-16752

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Circle Reader Action No. 313

Fuel-Cell Structure Prevents Membrane Drying

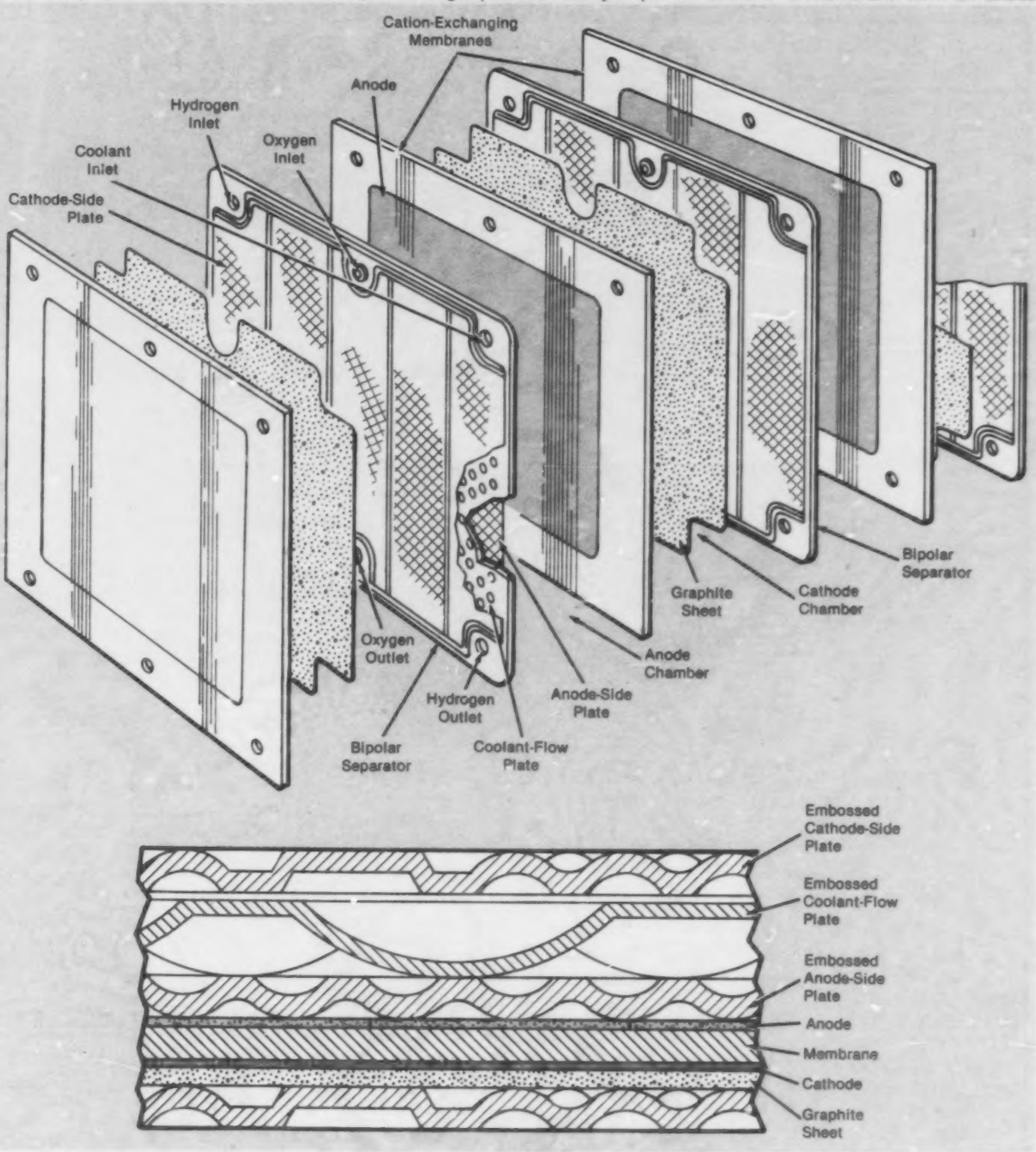
Embossed plates direct flows of reactants and coolant.

Lyndon B. Johnson Space Center, Houston, Texas

A membrane-type fuel-cell battery has improved reactant flow and heat removal. The compact, lightweight battery can produce high current and power without drying of its membranes.

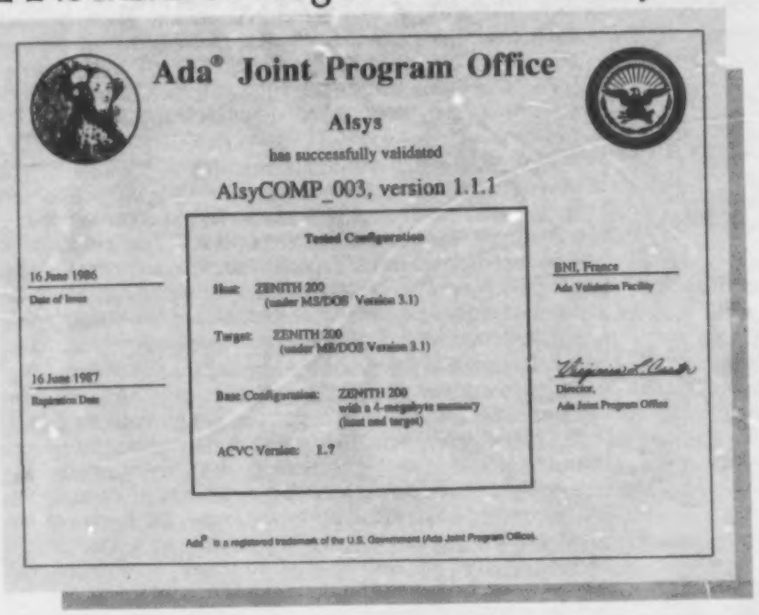
The battery consists of a series of fuel cells (see figure), each of which contains a cation-exchanging membrane between internally cooled bipolar separators. An anode is attached to one side of a membrane; the anode is an aggregate of liquid- and gas-pervious catalytic particles in a polymeric binder. A pervious cathode is bonded to the other side of a membrane; it too is composed of catalytic and binder particles.

The bipolar separators on opposite sides of a membrane form an anode



The Fuel-Cell Battery includes a series of membranes and separators. The anode graphite sheets, which support the cell membrane, do not appear in this view. The bottom part of the figure shows the internal structure of a separator in cross section.

Alsys validates Ada® compiler for Zenith Z-248 MS/DOS for government/military users.



Alsys has validated its Ada compiler for the Z-200 series of computers running under MS/DOS, including the Air Force and Navy contracted Z-248. The Ada Compiler, bundled with a 4 MB RAM board, is available in single unit quantities for $2,995.

The compiler, validated at the same time for the IBM PC AT, HP's Vectra, Compaq's Deskpro 286, Sperry's PC/IT, Tandy's 3000 HD and the Goupil/40 can convert general purpose desktop computers to program development workstations using the broadly mandated Ada language.

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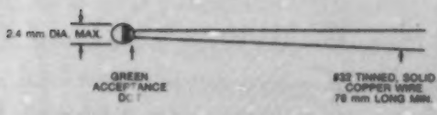

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chamber and a cathode chamber. Hydrogen gas is oxidized at the anode, releasing electrons to an external load circuit. The hydrogen ions thus created pass through the membrane to the cathode, where oxygen and electrons react with the hydrogen ions to form water. The water product collects at the bottom of the cell, where it drains away through the oxygen-outlet manifold. (Fuel/ oxidizer combinations other than hydrogen/oxygen may be used. The reactants may be hydrogen/chlorine or hydrogen/bromine, for example.)

Oxygen enters the cathode chamber through an inlet at the top of the bipolar separator. Hydrogen enters the anode chamber through an inlet at a corner of the separator. In the new fuel-cell configuration, the separator contains embossed plates on its opposite faces to guide the flowing gases— hydrogen on the anode side and oxygen on the cathode side. The plates distribute the gases uniformly for efficient reaction.

A coolant plate between the anode-side and cathode-side plates forms two adjacent chambers through which coolant flows. The cathode-side plate is made of niobium, 5 mils (0.13 mm) thick. The anode-side plate is made of zirconium, which is resistant to embrittlement by the hydrogen flowing over it. The coolant plate is made of titanium. The three plates are held together by the frame of the separator. The concave bumps embossed in the coolant plate on the cathode side tend to collect coolant, so that flow there is slower and removes less heat than does the flow along the anode side. The anode side of the cell membrane is therefore maintained at a temperature lower than that of the cathode side.

The effect of this temperature differential is to prevent drying of the hydrogen side of the membrane. Without the differential, as hydrogen is oxidized the resulting hydrogen ions move through the membrane, carrying molecules of membrane water with them. Because each hydrogen ion can carry eight to ten water molecules with it, the water on the fuel side can quickly become depleted. This drying effect, which is aggravated as the battery power output—and hence the cell current density—increases, can limit the maximum power output.

With the temperature differential, however, water diffuses from the warmer cathode to the cooler anode. This reverse diffusion compensates for the loss of water on the fuel side.

This work was done by James McElroy of General Electric Co. for **Johnson Space Center**. *For further information, Circle 111 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 27]. Refer to MSC-21031.

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Solenoid-Simulation Circuit

Electrical properties of solenoids are imitated for tests of control circuits.

Marshall Space Flight Center, Alabama

A simulation circuit imitates the voltage and current responses of two engine-controlling solenoids. Used in tests of the programs of the digital engine-control circuits, the solenoid-simulation circuit also provides an electronic interface with circuits that imitate the electrical properties of pressure sensors and linear variable-differential transformers (LVDT's).

The solenoid-return voltages in the real engine circuits are measured across sensing resistors placed in the engine-control panel and connected electrically in series with the solenoids. Thus, the solenoid-return voltages are proportional to the solenoid currents. The simulation circuit (see figure) puts out solenoid-return voltages that represent the solenoid pulling and holding currents. For the control-circuit tests, it is necessary to imitate a pulling level of current for a specified duration, followed by a holding level for an indefinite time.

Channels A and B represent the two solenoids. Power resistors R_A and R_B represent the coils of the corresponding solenoids. The time constants for charging the capacitors at the noninverting inputs of amplifiers A_1 and A_3 represent the times required to build up the solenoid current to the pull-in level. When the pull-in level is reached in channel A, amplifier A_1 sends a positive signal to the "set" input of flip-flop A to represent the discrete turn-on of solenoid A. Similar events occur in amplifier A_3 and flip-flop B when the simulated current of solenoid B reaches the pull-in level.

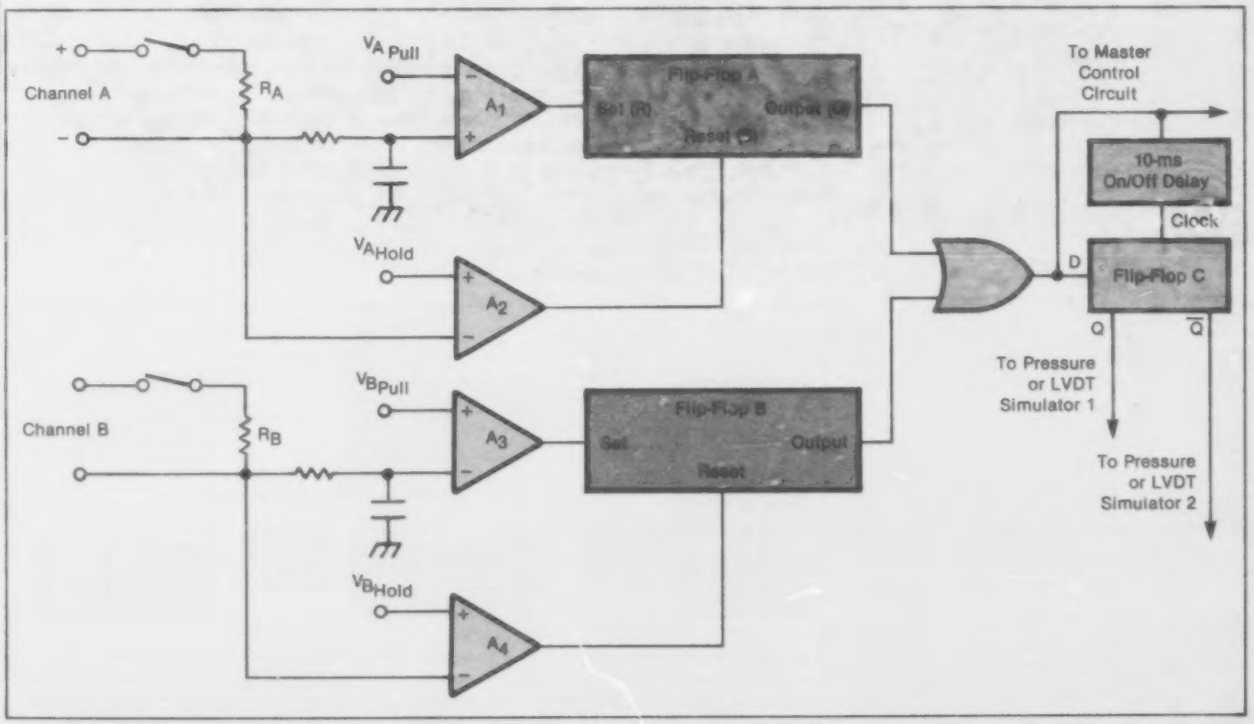
The flip-flop output of each channel continues to indicate that the solenoids are on as long as the simulated solenoid current in that channel equals or exceeds the holding level. When the simulated return voltage falls below the holding level in channel A, amplifier A_2 sends a positive signal to the "reset" input of flip-flop A, causing the flip-flop output to change and thereby indicating the turnoff of solenoid A. Again, similar events in amplifier A_4 and flip-flop B indicate the turnoff of solenoid B.

The "solenoid on" signal of either channel is fed through the OR gate to a master control circuit for use in monitoring the test and protecting the engine-control circuits. Delayed versions of the "solenoid on" signal are used to open and close LVDT simulations and to raise and lower pressure simulations. The delays prevent false triggering from erroneous inputs and simulate the delays encountered in real engine operation.

For each channel, a switch connects either of two sets of voltages representing two different sets of holding and pulling currents. This is to enable the simulation of two different types of solenoid or sensing resistor used in the real engine circuits. The circuit is built on a card with an edge connector, and numerous such identical cards are used in the total engine-simulation circuit. Thus, all the cards are interchangeable, yet each one can be programmed via its edge connector. Edge-connector programming can also include the simulation of faults or the connection of a real solenoid.

This work was done by Richard A. Simon of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 140 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 27]. Refer to MFS-29173.



The **Solenoid-Simulation Circuit** produces voltages, currents, delays, and discrete turnon and turnoff signals representing the operation of a solenoid in an engine-control relay. Many such circuits are used in simulating the overall engine circuitry.

Electronic Systems

Hardware, Techniques, and Processes

36 Improved Spectrometer for Field Use
37 Three-Frequency Water-Vapor Radiometer
38 Laser-Pulse/Fiber-Optic Liquid-Leak Detector

Books and Reports

41 Understanding Microwave Radiometers

Improved Spectrometer for Field Use

Instrument would give answers in the field without waits for lab processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed portable spectrometer for analyzing minerals in the field would generate spectral images like a camera and process the spectral data for real-time identification of materials. To identify an unknown mineral, the user would locate significant peaks in the displayed spectrum and match them to a spectrum in a portfolio of reference spectra. Alternatively, the user would call up a display of prerecorded spectra in the same wavelength region for comparison or allow the spectrometer to determine the best match automatically.

The new instrument would make it unnecessary to return the data to a laboratory or an equipment trailer for processing. In principle, it would accommodate a wide variety of minerals. The proposed spectrometer would extend the capabilities of the simpler two-wavelength instrument described in "Portable Radiometer Identifies Minerals in the Field" (NPO-15234), page 419, *NASA Tech Briefs*, Vol. 6, No. 4 (Spring/Summer 1982).

In the proposed instrument, reflected light from the terrain enters a telescope (see figure) and passes along an optical fiber to a grating spectrometer. The grating disperses the light passing through filters onto a linear array of about 1,000 individual photodetectors or a set of charge-coupled-device detectors. The array is electronically scanned so that it yields analog signals, which are processed by gain-adjusting circuits, amplifiers, and demodulators. The analog data from the signal processor are converted to digital form for use by a microprocessor. The microprocessor and a digital recorder provide signals for a liquid-crystal display.

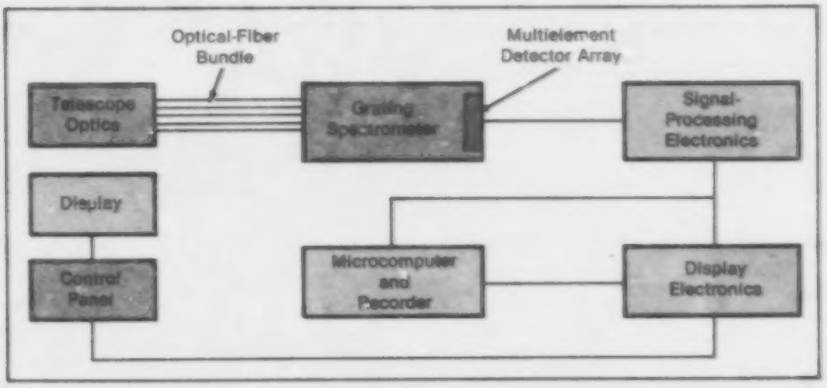
A control pad and spectral display are contained in a separate paddle so that the telescope can be made as light as possible. The user can select a portion of the reflectance spectrum of the surface under examination for real-time display, can expand the reflectance and wavelength display coordinates as desired, and can retain a spectrum for further processing and recording.

An initial calibration is carried out in ambient light, preferably with a target lighted by the Sun. The instrument is pointed at a standard-reflectance calibration target, and the spectrum is recorded.

The instrument is then pointed at the target terrain, and its spectrum, after ratioing with the standard, is displayed on the screen. The spectrum is recorded for future use. For analysis, prerecorded spectra are called up for comparison as a superimposed curve, or else algorithms are applied for automatic identification of the target specimen.

This work was done by Alexander F. H. Goetz of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 117 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 27]. Refer to NPO-15732.



Telescope Optics Are Separated from the display and the control panel so that the instrument is easy for a user to operate. Once a sizeable library of prerecorded reference spectra is accumulated, spectrum-matching algorithm boards can be incorporated into the miroprocessor to evaluate rapidly the components of a target specimen.

Three-Frequency Water-Vapor Radiometer

Measurements increase the accuracies of delay predictions.

NASA's Jet Propulsion Laboratory, Pasadena, California

A three-frequency microwave radiometer measures the quantity of water vapor in the atmosphere, as part of the effort to determine microwave-signal delays due to water vapor. The delay estimates are necessary for the accurate determination of distances in geodesy and such related applications as very-long-baseline interferometry. The water-vapor data are also directly useful in weather research.

The amount of water vapor and the microwave delay caused by the water vapor along a line of sight in the atmosphere are readily estimated from microwave observations along the same line of sight. in prior radiometer systems, the most important measured quantity was the thermal atmospheric emission at a frequency near the 22.237-GHz resonance of the H_2O molecule. In cloudy skies, a second measurement was made away from this resonance to determine the thermal contribution from liquid water. The new radiometer measures the emission at three frequencies, two (20.7 and 22.3 GHz) near the resonance and a third at 31.4 GHz. The three-frequency technique offers a modest improvement in delay estimation over the two-frequency technique.

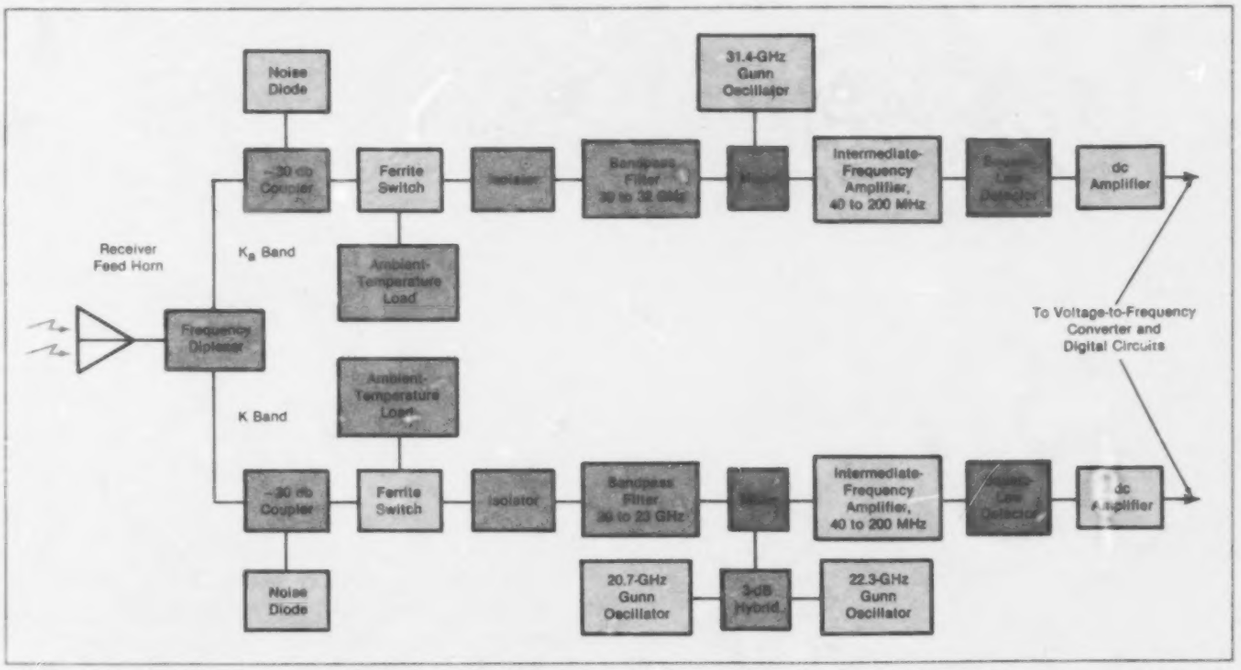
The figure illustrates the microwave portion of the radiometer. The received sky signal is fed through a frequency diplexer, which separates the two lower frequencies from the higher one. The individual receivers are Dicke radiometers, each of which includes a ferrite switch to alternate its input between the received sky signal and an internal ambient-temperature load for temperature calibration and receiver stabilization. A constant white-noise signal from a noise diode is coupled into the sky-signal port of each ferrite switch to provide a gain-calibration reference.

The mixers are of the double-balanced, Schottky-diode type having intermediate-frequency passbands of 40 to 200 MHz. The 20.7- and 22.3-GHz signals are obtained in the lower frequency channel by passively coupling the two Gunn local oscillators into the mixer and alternately turning the oscillators on and off. The bandpass filters suppress the local-oscillator harmonics, that might otherwise cause offsets in the Dicke comparison between the sky- and ambient-temperature reference ports.

All of the radiometer components except the receiving feed horn are configured in a plane and fastened to an aluminum heat sink. The heat sink is thermally isolated from the environment except for a thermoelectric heat pump that maintains it at 35 °C. This temperature control stabilizes the radiometer gain and noise-diode outputs within a small fraction of a percent.

A microprocessor monitors temperatures, power-supply voltages, and the output of a tilt sensor for automatic zenith-angle calibration. It controls the stepping motors that change the line of sight. It also controls the microwave switches. One cycle of the switching sequence takes about 1 s and is comprised of eight integration subcycles of about one-eighth s at each of the eight combinations of switch positions. The radiometer outputs are integrated digitally and processed into sky-brightness temperatures.

This work was done by Michael A. Janssen and Noburu I. Yamane of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 124 on the TSP Request Card.*
NPO-16531



The **Water-Vapor Radiometer** measures thermal emissions from the sky at three microwave frequencies to determine the water-vapor content of the atmosphere and the consequent wet-path microwave delay.

Laser-Pulse/Fiber-Optic Liquid-Leak Detector

Several potential leak sites can be monitored using a single sensing fiber.

John F. Kennedy Space Center, Florida

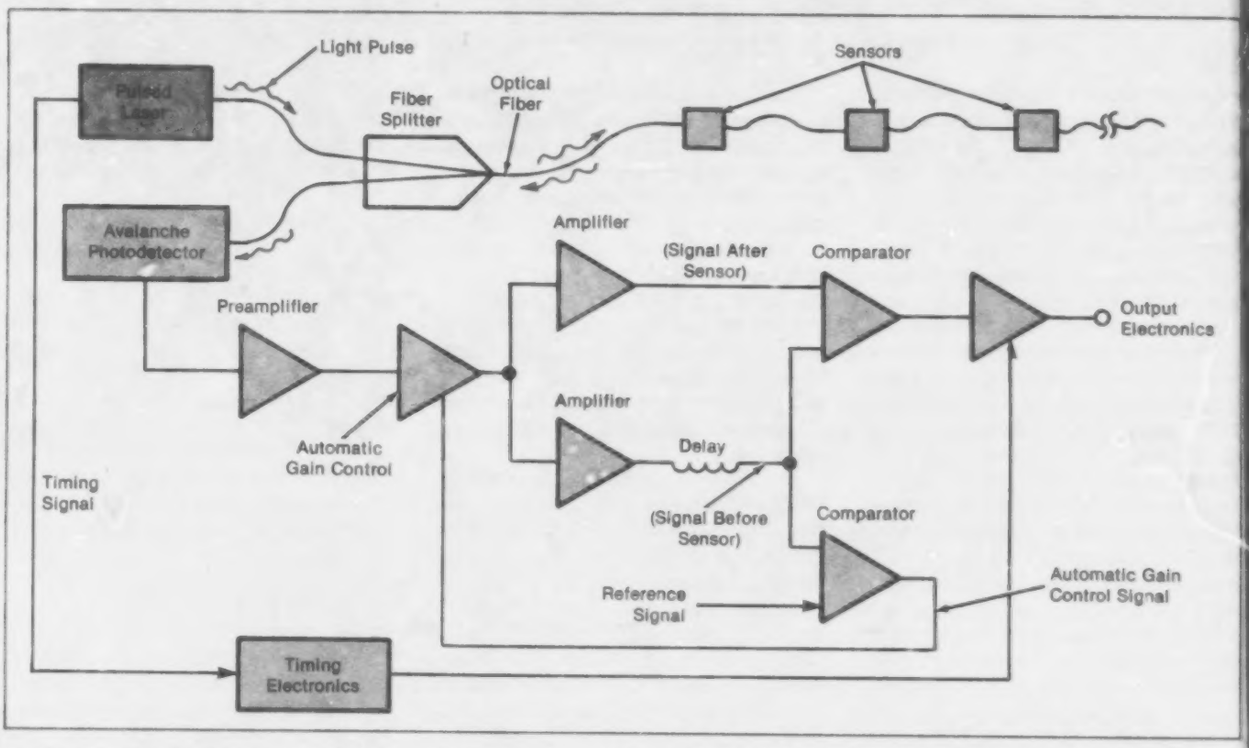


Figure 1. This **Optical Time-Domain Reflectometer** measures pulse travel times to identify the sensor or sensors from which reflected laser pulses originate. A leak is indicated by a change in the amplitude of the pulse reflected from a sensor.

Fluid systems can be monitored quickly for leaks in remote, hazardous, or inaccessible locations by a system of compact, lightweight fiber-optic leak sensors that are presently undergoing development. The sensors would be installed at such potential leak sites as joints, couplings, and fittings. A sensor is read by sending a laser pulse along the fiber, then noting the presence or relative amplitude of the return pulse. This leak-monitoring technique should be applicable to a wide range of fluid systems and would minimize human exposure to toxic or dangerous fluids.

The sensors are optical discontinuities from which light is reflected back along the sensing optical fiber or fibers to a photodetector. The intensity of the reflection is determined in part by the index of refraction of the medium surrounding a sensor, through its effect on the electromagnetic modes in the fiber core and cladding. For example, if leaking oil having an index of refraction near that of the cladding comes into contact with the cladding, a substantial amount of light is coupled out of the core and lost to the en-

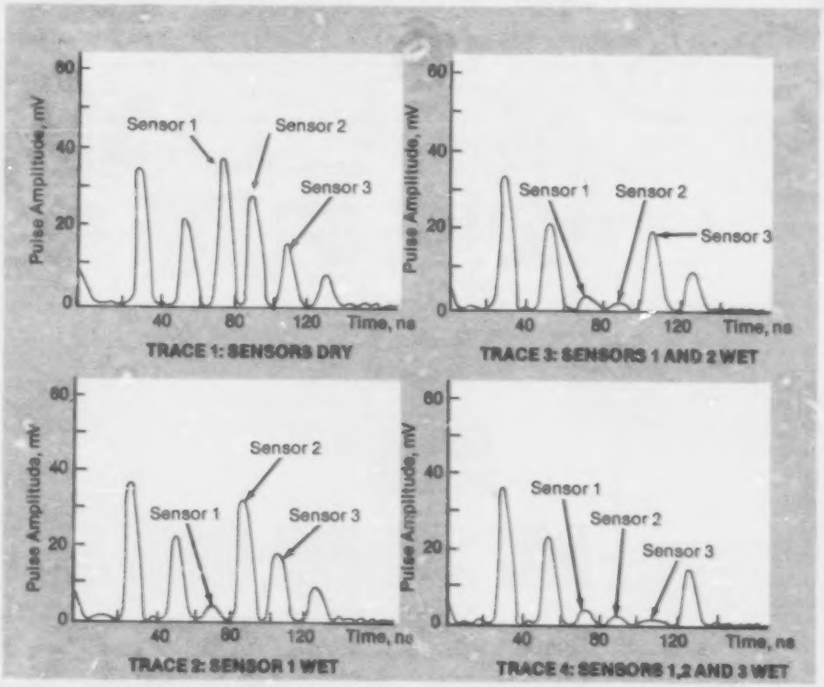
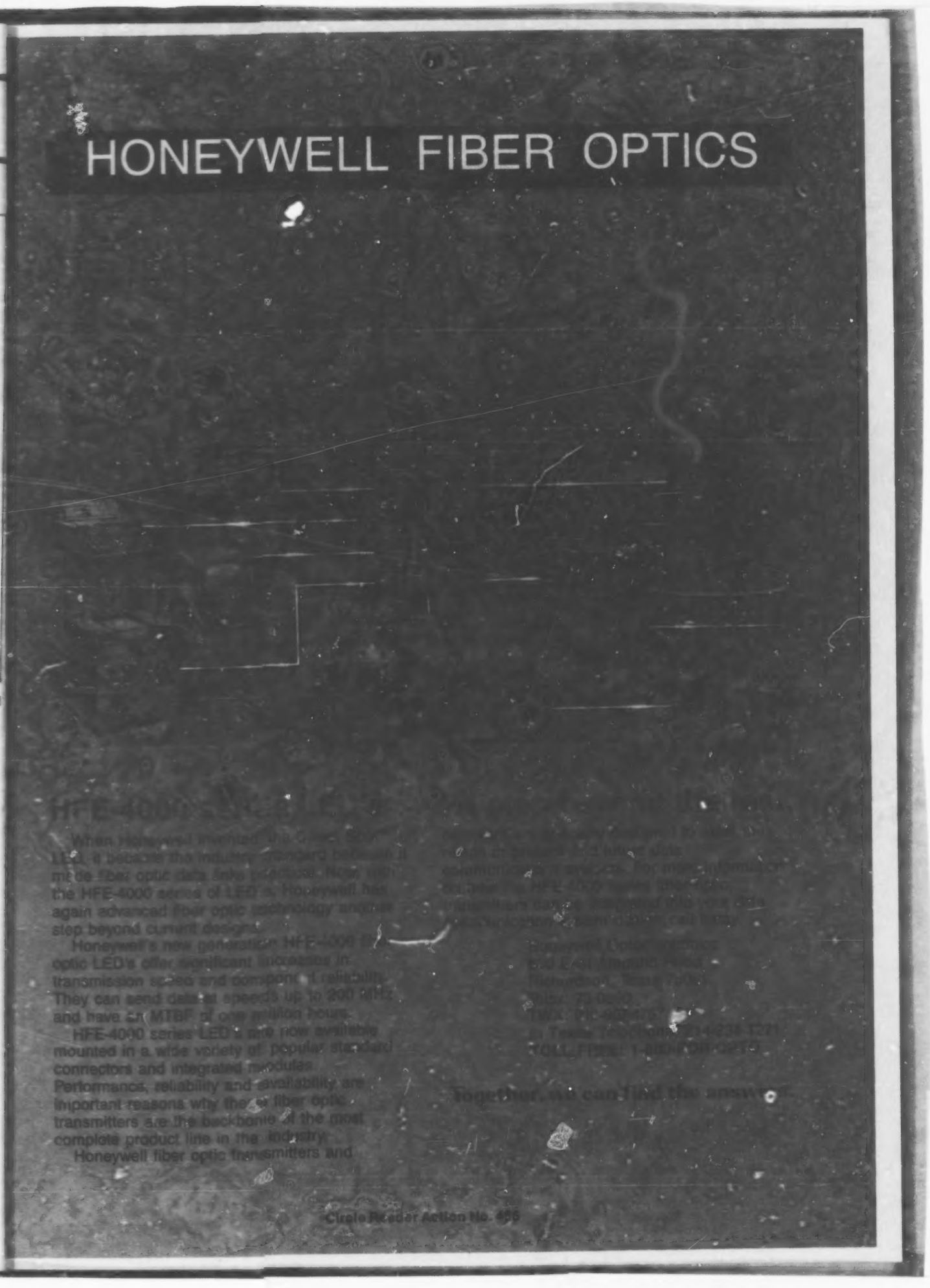


Figure 2. The **Presence of Water at Sensors** connected in series is shown by the reduction of the corresponding reflected laser pulses. The reflections from the dry sensors are indicated by peaks 3 through 5 in the first trace. The subsequent traces show the effects of successively wetting the three sensors.


HONEYWELL FIBER OPTICS

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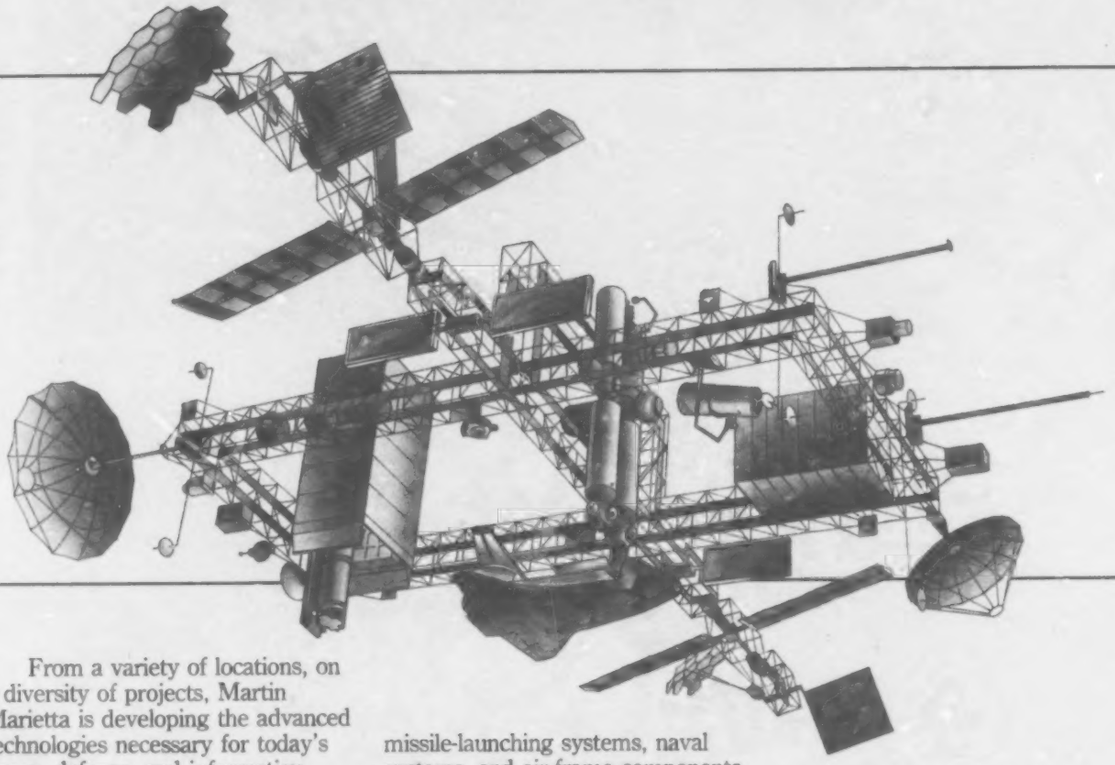

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vironment. In this case, the loss of reflection would indicate a leak.

The types of sensors showing the most promise include tapered constrictions, U-bends, and tilted fiber ends with and without mirrors. An individual fiber could be run to each potential leak site, which would necessitate large amounts of fiber. Alternatively, optical time-domain reflectometry can be used, as shown in Figure 1. There, the sensors are located in series along one fiber. The travel time of an affected pulse indicates the distance along the fiber to the affected sensor, thereby identifying the leak. Calculations indicate that 50 to 100 sensors can be connected along one optical fiber.

Figure 2 shows the signals reflected from a chain containing three experimental sensors in series, approximately 2 m apart. The first two returned pulses are from the connectors between the fiber and sensor chain. The next three pulses are reflections from the three sensors. The last pulse is from the end of the fiber. As can be seen, wetting one sensor increases the signal from subsequent sensors.

This work was done by Michael E. Padgett of **Kennedy Space Center** *and Opto-Electronics, Inc. For further information, Circle 136 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center [see page 27]. Refer to KSC-11331.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Understanding Microwave Radiometers

A tutorial document aids in designing these useful instruments.

A report presents the principles of microwave receivers for observing planetary surfaces from space. The report is tutorial in nature and explains the operation of the receivers in enough detail to enable the reader to specify and qualify them for spaceborne operation. It gives many examples to illustrate practical design procedures.

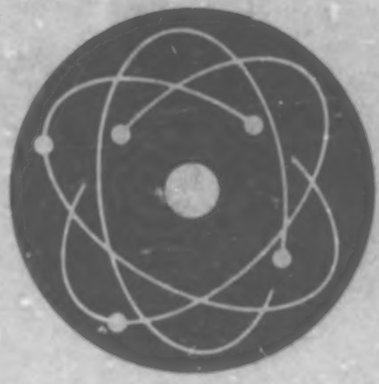
A microwave radiometer is the heart of a radio-astronomy facility. In fact, astronomers have been largely responsible for the major technical refinements in today's radiometric equipment. Commercial users and the military have been slower to accept microwave radiometry, probably because more mature sensors and methods have been available to them. Nevertheless, the remote sensing of the atmosphere and surface of the Earth from space has emerged as a potentially useful but incompletely developed application for microwave radiometry. Ultimately, the disciplines most likely to benefit are glaciology, hydrology, meteorology, and oceanography.

The report discusses the principles of operation of the key components of a receiver. It explains the important differences among receiver types. It develops new definitions as necessary — when concepts have not been defined previously, for example, or when there is no universally accepted definition.

Mathematical expressions are derived for operating performance and sensitivity for both the modulated and total-power receiver configurations. Applied statistics has been rigidly adopted for precision in interpreting derived quantities and in explaining uncertainties. Examples illustrate, from a thermodynamic perspective, the transfer of energy from point to point in the receiver.

This work was done by Joseph M. Stacey of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "Spaceborne Receivers — Basic Principles," Circle 141 on the TSP Request Card.*
NPO-16586

Physical Sciences



Hardware, Techniques, and Processes

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Photocurrent Imaging Detects Solar-Module Defects

A raster-scanned laser beam excites photocurrents in thin-film amorphous silicon devices.

NASA's Jet Propulsion Laboratory, Pasadena, California

Cracks in thin-film amorphous silicon solar modules show up as dark lines on the image from a new solar-cell laser scanner. As a monochromatic laser-beam spot < 1 mm in diameter scans in a raster over a forward-biased solar module, the resulting photocurrent is displayed as brightness on a television monitor (see Figure 1) scanned in the corresponding raster.

While the solar-cell laser scanner will not replace other commonly used test

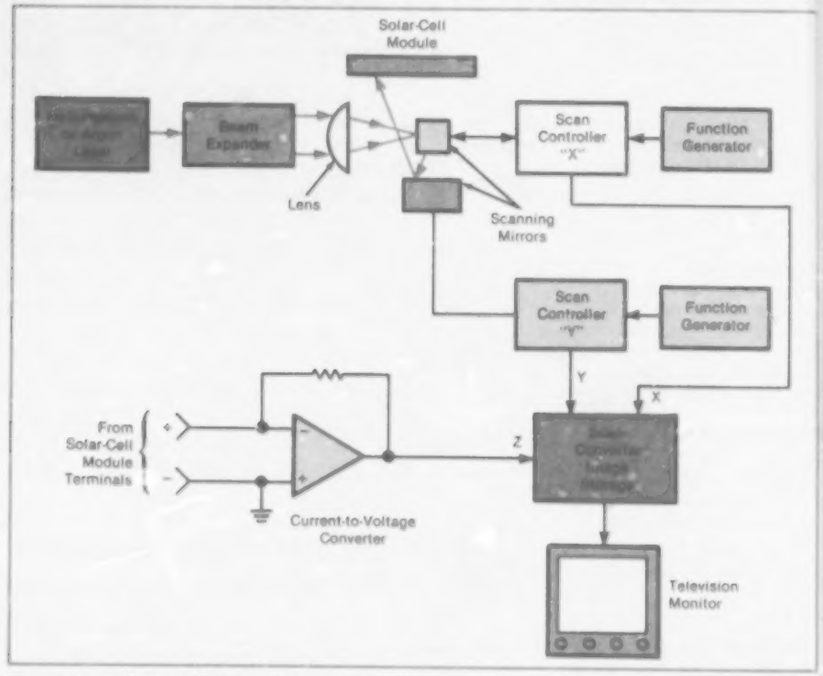


Figure 1. The **Solar-Cell Laser Scanner** uses two galvanometer-driven mirrors to scan a laser-beam spot over the surface of the module or cell under test. Position signals from the scan controllers are used to index the storage of the photocurrent signal data in the scan-converter image memory. The stored image is displayed on a television monitor.

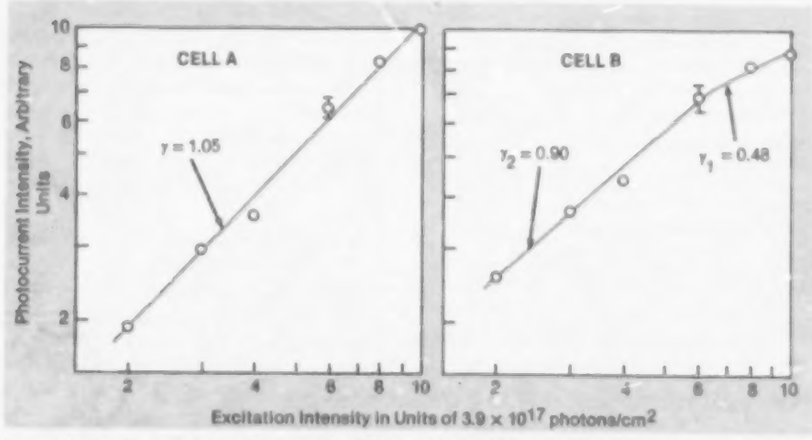
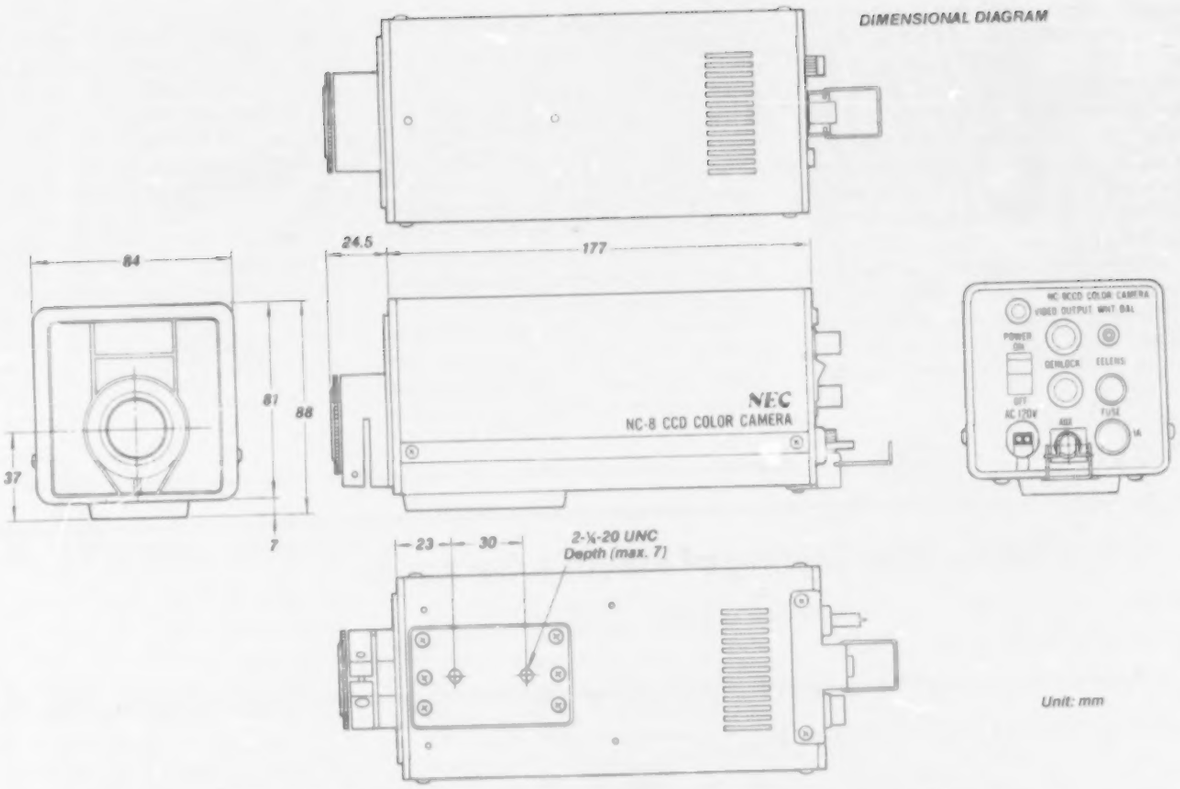


Figure 2. The **Photocurrent Measured at Different Excitation Intensities** can be used to study the physical characteristics of a cell or of a small portion of a cell. Here, two graphs show the independence of the photocurrent on the excitation intensity for two different amorphous-silicon cells in the same array.

DIMENSIONAL DIAGRAM



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Pickup	Interline transfer type CCD x1
Number of picture element	H427xV492
S/N ratio	47dB (illuminance channel, standard recording conditions, AGC: off)
Resolution	Horizontal: 280 lines Vertical: 350 lines
Sensitivity	1,600 Lux F4.0
Minimum illumination	10 Lux F1.4 AGC: ON (20% signal output level)
White balance adjustment	Manual/Remote
Lens mount	C-Mount
Power consumption	Approx. 6.5W (less than 9VA)
Weight	Approx. 1.4kg (3.1 lbs) (excluding lens)

For more information about the NC-8, TI-22AII, TI-22PII and TI-26A industrial cameras, contact the Industrial Video Group, Broadcast Equipment Division, NEC America, Inc., 1255 Michael Drive, Wood Dale, IL 60191 Toll free 1-800-323-6656. In Illinois phone 312/860-7600.

Circle Reader Action No. 369

and inspection techniques, it should be very useful for the nondestructive evaluation and analysis of failure of entire solar modules or individual cells. No special electrical connections are required: The test uses the normal electrical contacts of the cell. No special environment is needed, and cells can be tested whether or not they have been encapsulated.

Additional characteristics of the cells may be inferred by a study of the effects of the excitation intensity on the photocurrent images. Variations in the dependence of the photocurrent on excitation may be valuable indications of cell quality. For example, the photocurrent responses of two cells of an array are shown in Figure 2. Each cell had a positive/intrinsic/negative structure with the light reaching the optically active intrinsic layer through a transparent conducting SnO_2 layer. Since the excitation intensity in the beam spot was relatively high (5 to 10 Suns), the dependence of the photocurrent, I, on the excitation intensity, F, was fit to an equation from free-carrier transport theory; namely, $I \propto F^{\gamma}$.

The value $\gamma = 1.05$ for cell A may be indicative of uniformly distributed trap states. The values $\gamma = 0.90$ and 0.48 for the two regions of differing slope in cell B are consistent with the recombination kinetics associated with deep gap states and an exponentially distributed band tail of shallow trap centers. These results may indicate that the recombination and trapping characteristics of the two cells are quite different, even though both were fabricated by the same process.

This work was done by Quiesup Kim, Alex Shumka, and James Trask of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 94 on the TSP Request Card.*
NPO-16658

Furnace for Tensile Testing of Flexible Ceramics

Ceramic cloth and thread are tested quickly at temperatures up to 1,250 °C.

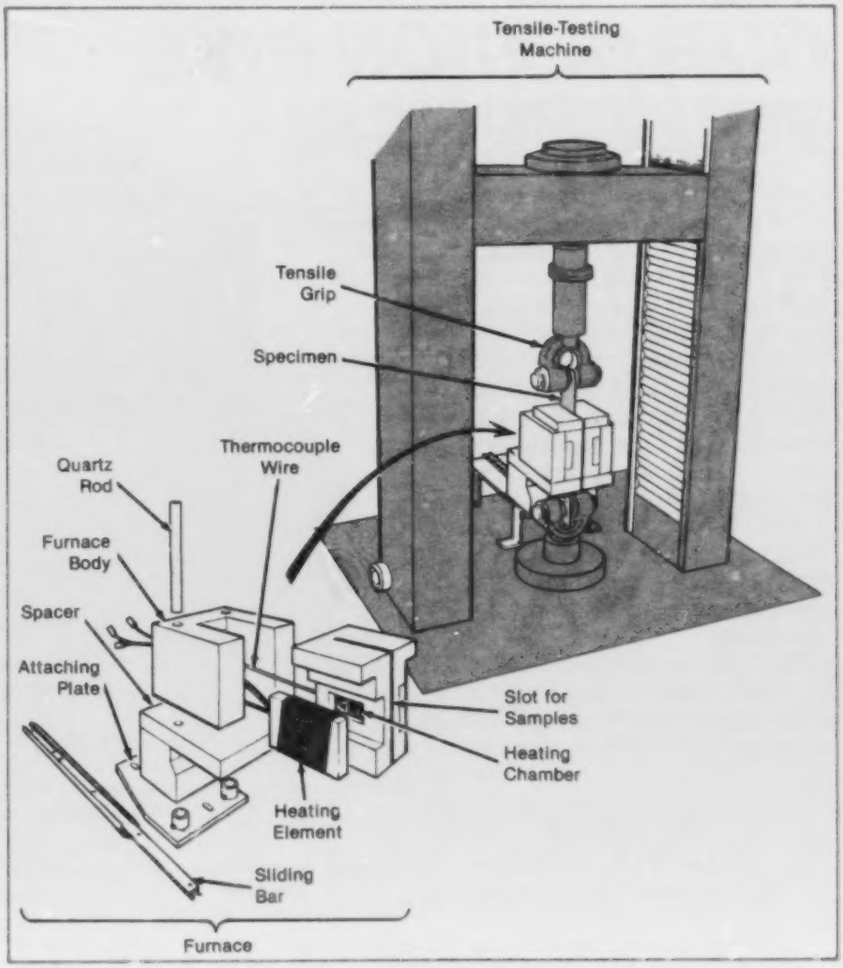
Ames Research Center, Moffett Field, California

Tensile strengths of ceramic cloths and threads can be measured conveniently in a new furnace at specified temperatures up to 1,250 °C, using an ordinary mechanical tester. The samples are heated along part of their lengths in the furnace slots. The interchangeable furnace chambers and the matching heating elements are sized to match the size of the tested ceramic material.

The furnace is made of foamed silica with temperature-controlled embedded resistant-wire heating elements powered by a 110-V, 25-A supply. Designed to heat strips about 1 in. (2.5 cm) wide or threads that are less than 0.06 in. (0.15 cm) thick, the furnace is 4 in. (10.2 cm) wide, 5 in. (12.7 cm) deep, and 3 in. (7.6 cm) high. The furnace test chambers are one-half in. long, one-half in. wide, and 1 in. high (1.27 by 1.27 by 2.54 cm) for thread, and 1-1/2 in. long, one-half in. wide, and 1 in. high (3.81 by 1.27 by 2.54 cm) for cloth.

There are two type "K" thermocouples — one for the temperature control, the other for temperature monitoring — mounted one-eighth in. (3 mm) from the tested material. The small furnace opening — a 1/16-in. (1.6-mm) slot — allows the furnace to be slid into place around, or removed from, the specimen, with insignificant loss of heat at the test temperature.

The tensile-test specimen is mounted in the mechanical tester with a 4-in. (10.2-cm) opening between the tensile grips (see figure). Mounted on a horizontal sliding bar, the preheated furnace is moved forward to enclose the tensile



The Modular Design of the Furnace allows the tensile-strength testing of both ceramic thread and cloth.

specimen, the strength of which is then measured in the standard way. After the specimen breaks, the furnace is moved away from the test specimen, a new specimen is mounted in the tensile grips, and the furnace is slid into place for the next test. Because the furnace remains hot and does not enclose the mechanical tester, no time is lost waiting for the furnace to reheat.

This work was done by Marnell Smith, Carlos A. Estrella, and Victor W. Katvala of **Ames Research Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center *[see page 27].* *Refer to ARC-11589.*

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Star-Viewing Scheduler

A strategy and an algorithm produce a well-balanced timetable that accommodates many constraints.

A strategy for scheduling star observations on Space Shuttle astronomy missions ensures the best use of the three future ultraviolet telescopes. The strategy, which is described in a report, takes into account such diverse factors as maneuvers of the Space Shuttle orbiter, interference by the Moon, occultation by the Earth, reflections, unstaffed periods during crew rotation, encounters with the South Atlantic anomaly, and obscuration during the dispersal of ejected water.

On the basis of these factors, the strategy determines observation intervals that are fed to an algorithm, ASTRON. The algorithm determines which of the more than 200 candidate targets will be viewed during each of the intervals and arranges them in an observation sequence. ASTRON determines the observation schedule well in advance of a mission. It takes only 10 minutes of computer time to produce a schedule that is optimized, efficient, error-free, and well balanced.

The algorithm incorporates five criteria, each with a weighting factor chosen by the user: (1) the duration of the specific target interval, (2) the total requested observation time, (3) the total duration of all intervals for the particular target remaining until the end of the mission, (4) the telescope sluing time, and (5) the target priority. In addition to the time for moving the telescope to a target, the sluing time includes the time for instrument settling, acquiring the guide star, and waiting for the target to rise.

The algorithm uses a "Cinderella" logic loop to take advantage of the best viewing conditions, which occur during orbital night. The loop forces night observations to begin at Sunset, thereby keeping the relatively large maneuvers between day and night targets completely in orbital day. This results in high nighttime efficiency and prevents lower priority observations from migrating at random into orbital night.

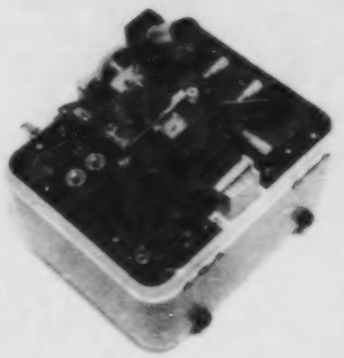
Thresholds related to instrument sensitivity and observation-program requirements are taken into account. For example, the instruments require at least 500 seconds to obtain usable data. All candidate targets are therefore screened to ensure that they are available for this minimum period. There are also certain observations that require a larger minimum and that cannot be interrupted. The algorithm is designed to accommodate these special cases.

This work was done by Orville T. Guffin of **Marshall Space Flight Center** *and Barney H. Roberts and Phillip L. Williamson of Boeing Computer Support Service. To obtain a copy of the report, "Astronomy Scheduler (ASTRON)," Circle 9 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center *[see page 27].* *Refer to MFS-28089.*

Power Technology Inc.

OPTICAL FIBER SPLICER



From assembly line production to the rugged environment of field repair, the PFS-200 will consistently provide low loss splices (as low as .05db) for single or multimode silica or glass fibers. The unit operates from a wide variety of external power sources or from built-in rechargeable batteries, making it ideal for lab work, field installation and field repair of optical fibers.

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- Internal batteries automatically recharge when unit is connected to a 110/220VAC source.
- Power from built-in batteries provide approximately 400 splices per charge.
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- Weighs only 22 pounds (9.8kg).

Power Technology Incorporated

P.O. BOX 9769
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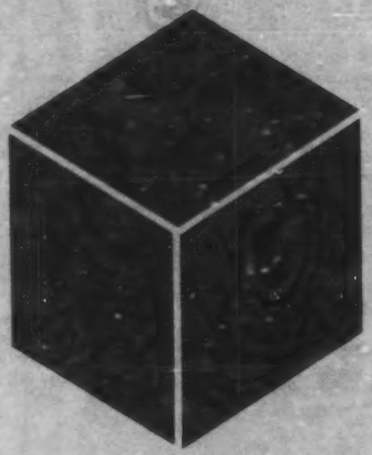
PHONE 501-568-1995
TWX 910-722-7313

Circle Reader Action No. 320

Materials



Hardware, Techniques, and Processes

46 Hose- and Tube-Cleaning Module
48 Fire-Resistant Belt Panel for Airplane Windows
48 Fire-Resistant Aircraft Ceilings
51 Two-Step Vapor/Liquid/Solid Purification
52 Strong Adhesive Tape for Cold Environments
54 Fuel Manifold Resists Embrittlement by Hydrogen
54 Iron/Phosphorous Alloys for Continuous Casting
55 Polyether/Polyester Graft Copolymers
56 Low-Resistivity Zinc Selenide for Heterojunctions

Books and Reports

59 Chemical Characterization of Phenol/Formaldehyde Resins

Hose- and Tube-Cleaning Module

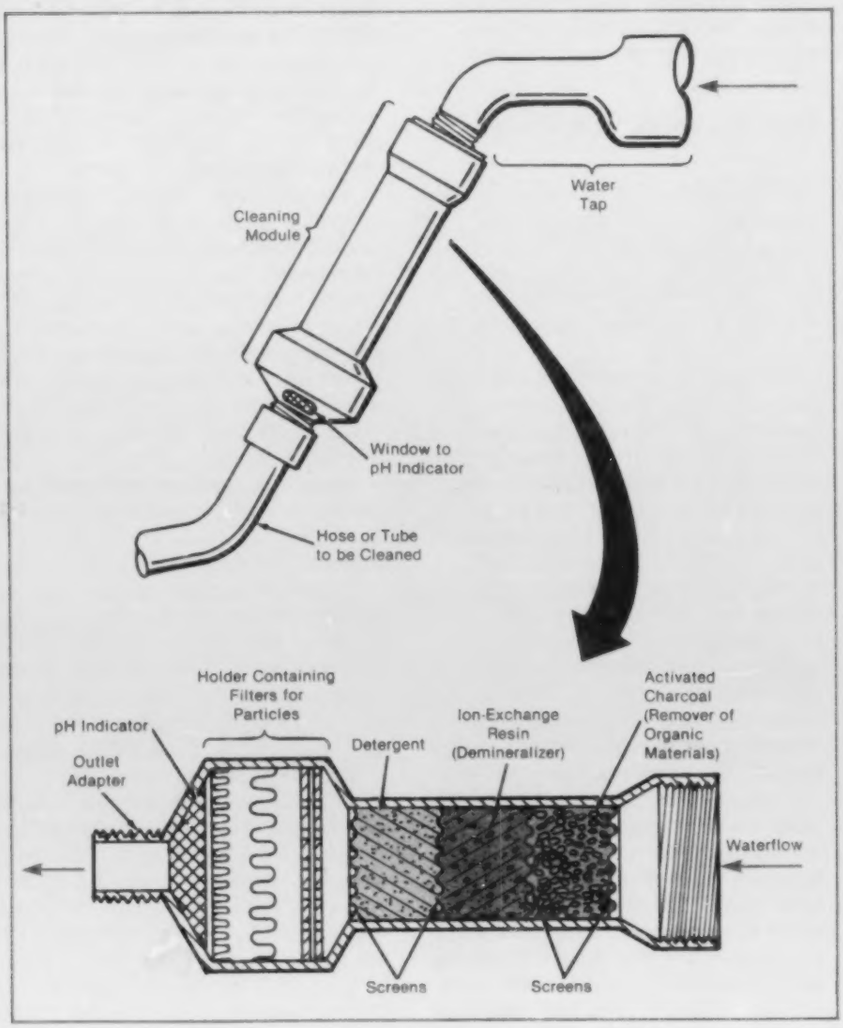
This device enables tubes and hoses to be cleaned easily, without other special equipment.

Lyndon B. Johnson Space Center, Houston, Texas

A self-contained, single-use module would enable a hose or tube to be cleaned thoroughly in the field, in one operation, using water of unknown or questionable quality. Previously, chemicals for flow cleaning had to be mixed, diluted, and pumped through tubes and hoses in many successive steps; moreover, deionizers, water-treatment facilities, and chemical storage were required. With the proposed device the cleaning can be performed safely, without special training. Ready to use, this device could be packaged as a cleaning kit with the tube to be cleaned.

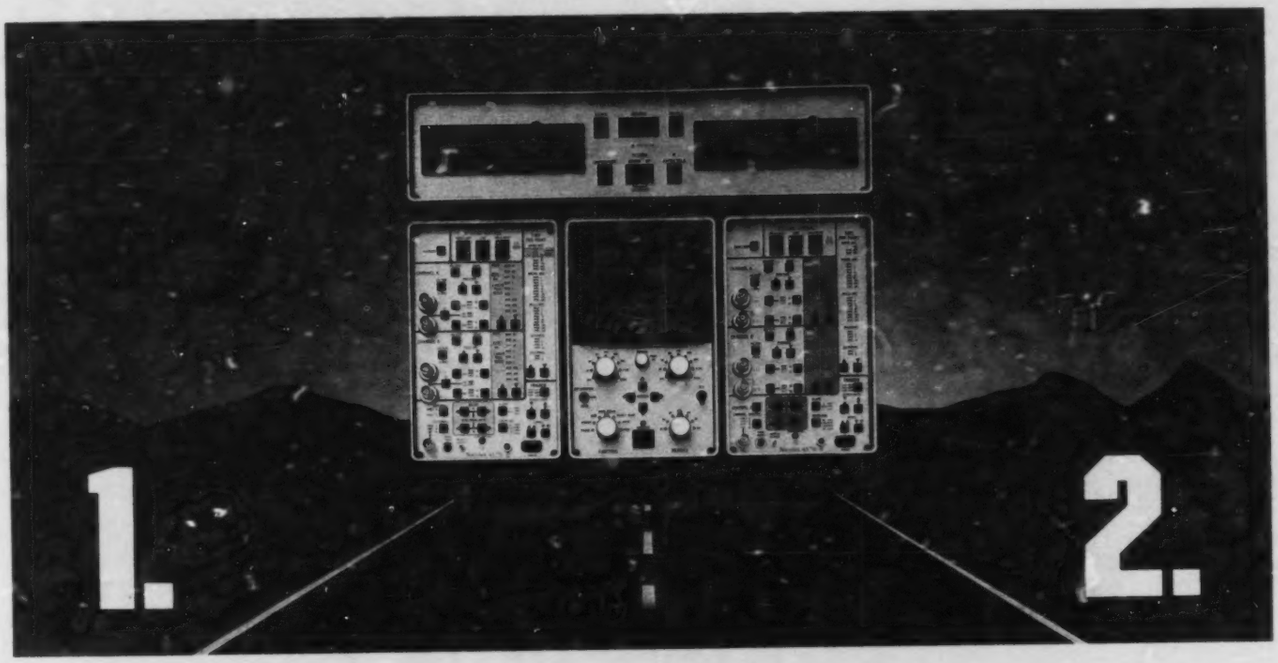
Shown in the figure, the device includes a housing of polyethylene (or other polymer) with an adapter for a water tap at the inlet end and an adapter for the specific application at the outlet end. Beginning at the inlet end, the tube contains a mesh screen to prevent the entry of large particles. The screen also retains a layer of activated carbon particles, which remove organic contaminants in the water flowing into the device.

The activated carbon is followed by another screen and a layer of ion-exchange resin, which removes dissolved minerals. Following the resin is another retaining screen and a layer of water-soluble powdered cleaning compound. Next is a retaining screen followed by a

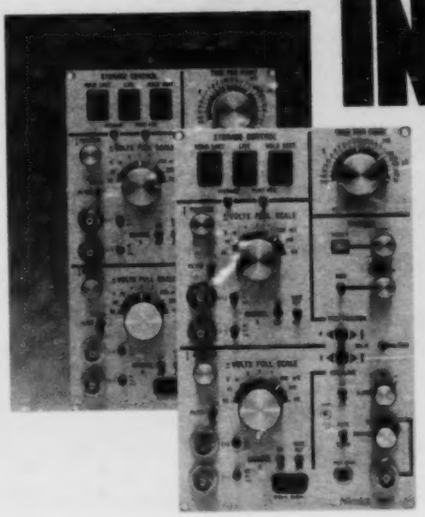


In this **Cleaning Module**, water entering through the inlet fitting is freed of organic matter by activated charcoal, then demineralized by ion-exchange resin, then laden with detergent, and finally filtered, before flowing to the hose, tube, or other system to be cleaned.

THE FIRST NAME IN DIGITAL SCOPES



TWO DIGITAL SCOPES IN ONE.



The Acquisition.

With sweep speeds from days to nanoseconds and resolution up to 15 bits, the 4094 digital 'scope can capture the most elusive signals. Every plug-in has 16K of memory, viewable trigger set-up and independent pre- or post-trigger delay on each channel. Signal averaging is standard and our latest 10 MHz/12-bit plug-in even offers real time manipulation of the incoming signals. With two plug-ins the 4094 can record four channels simultaneously. Or even monitor two slow signals and capture high speed glitches at the same time. All under computer control or via manual operation: whatever your application demands.

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Nicolet

Circle Reader Action No. 438

stack of filters of decreasing size to remove particles from the waterflow.

The filtration zone has a cross section larger than that of the preceding zones to reduce the speed and the pressure drop of the water across the filters. This protects the filters from tearing or breaking and enables them to remove finely divided particles that might remain. The outlet cone of the filter stack contains an embedded litmus or pH chemical indicator to show when the detergent supply is exhausted. The indicator color change is viewed through a window in the filter holder. Alternatively, the housing could be made of transparent or translucent material through which the color change could be viewed.

The device inlet is attached to the water supply. The outlet is attached to the hose or tube to be cleaned. The detergent-laden flow cleans the hose or tube as long as detergent is dissolving in the cleaning device. The flow may be stopped at any time to permit a soaking period. The water is allowed to run until the detergent is depleted, as shown by the change of color in the indicator caused by the decrease of the pH. After this, the water is allowed to flow awhile longer so that the hose or tube is rinsed.

The selection of the materials for the four module zones and the sizes of the zones are based on the contamination expected in the water and on the expected specific cleaning problem. The carbon absorber and the deionizer are made large enough to permit a rinse of sufficient duration or volume following detergent exhaustion. Additional units without detergent could be used for rinsing only, or for partial purification of water for drinking. After use, the module can be discarded; with simple modifications, a reusable device could be constructed.

This work was done by Fred P. Rollins and James S. Glass of Lockheed-EMSCO for **Johnson Space Center**. *For further information, Circle 93 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center [see page 27]. Refer to MSC-20857.

Fire-Resistant Belt Panel for Airplane Windows

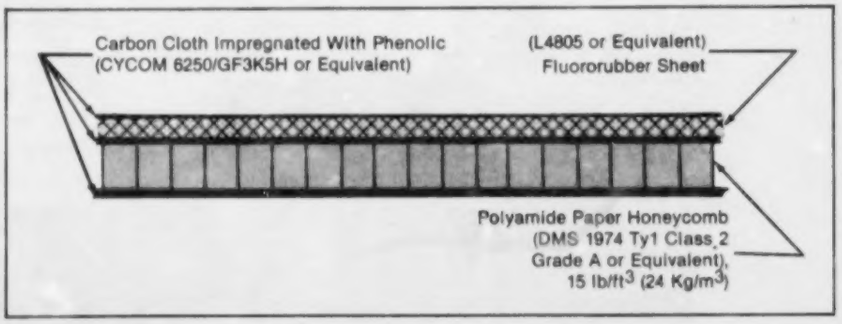
The layered structure incorporates materials that generate little smoke.

Lyndon B. Johnson Space Center, Houston, Texas

A window-belt panel for airplanes is fire resistant and generates little smoke when exposed to flames. The panel incorporates a fire-shield layer that adds minimal weight but delays or prevents a fire from burning through.

The structural core of the panel (see figure) is a Nomex (or equivalent) polyamide paper honeycomb. The fire shield, made of fluororubber sheet, is incorporated in a multiple-ply facing bonded to the core. The outer layers of the multiple-ply facing and the back face of the panel consist of biwoven carbon-cloth impregnated with phenolic resin.

A conventional belt panel consists of a Nomex (or equivalent) polyamide honeycomb core with a phenolic-resin-impregnated glass-cloth facing and a back-surface ply of epoxy-resin-impregnated glass-cloth reinforcement. The impregnated carbon cloth in the new panel weighs less than the glass cloth and gives off less smoke. The fire-shield layer in the new panel causes only a slight net increase in weight, yet significantly enhances passenger protection by delaying burn-through.



The Multiple-Ply Structure of the window-belt panel provides strength and fire resistance at low weight. Such standard parts as windows, shade assemblies, and air grills can be attached to the panel.

This work was done by Edward L. Trabold and Meade F. Murphy of McDonnell Douglas Corp. for **Johnson Space Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 27]. Refer to MSC-21064.

Fire-Resistant Aircraft Ceilings

New materials retard flames but keep panel strong and light.

Lyndon B. Johnson Space Center, Houston, Texas

A ceiling panel for airplane cabins is more fire resistant than conventional panels. The new panel incorporates a core of polyimide foam as a fire shield. The core significantly delays burn-through by flames and thus offers passengers greater protection.

Biwoven carbon cloth impregnated with precured phenolic resin is glued to both faces of the polyimide core for reinforcement (see figure). In a conventional panel, the core is an aramid

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CORNING

Circle Reader Action No. 454

Red Horizon (1981), acrylic on canvas, 10' x 6'. Norman Zammitt. In mixing and preparing colors for a painting, the artist uses computer generated logarithmic progressions; a kind of electronic palette. These mathematical sequences help determine the exact relationships of individual colors that collectively achieve a "blend." Following these calculations, he weighs precise amounts of color together on a gram scale. Five colors are used to create a total of forty-eight differentiated colors. After they are mixed and painted in order, they represent a harmony of extremes: of light and gravity.

The art and science of innovation. Given the talent and the technical tools, an individual can see what lies beyond the known. Determine its most effective use. And precisely measure its impact.

Through the technology and creativity of the Aerojet Propulsion Research Institute, exotic aerospace concepts are being transformed into tangible reality. Our Future Missions Group is exploring what will be humankind's boldest endeavors, while our Scientific Groups are determining how to overcome any obstacles that may exist.

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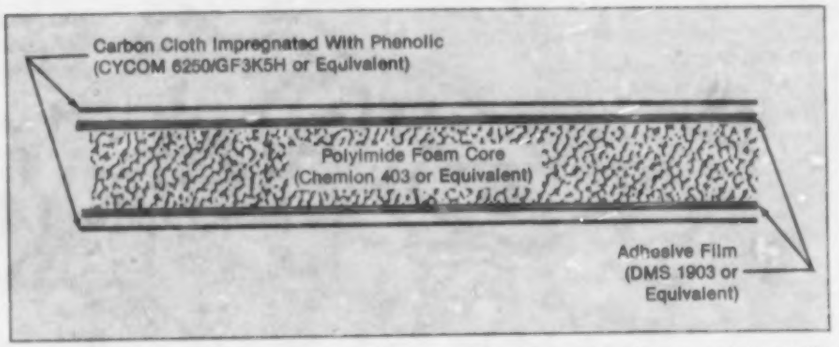
Circle Reader Action No. 386

paper honeycomb, and the reinforcing layers are phenolic-impregnated glass cloth. Although the new core material weighs more than the old, the new reinforcing layer maintains panel stiffness and weighs less than the old reinforcing material. The net weight gain associated with the greater fire resistance is therefore minimal.

This work was done by Edward A. Trabold and Meade F. Murphy of McDonnell Douglas Corp. for **Johnson Space Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 27]. Refer to MSC-21065.



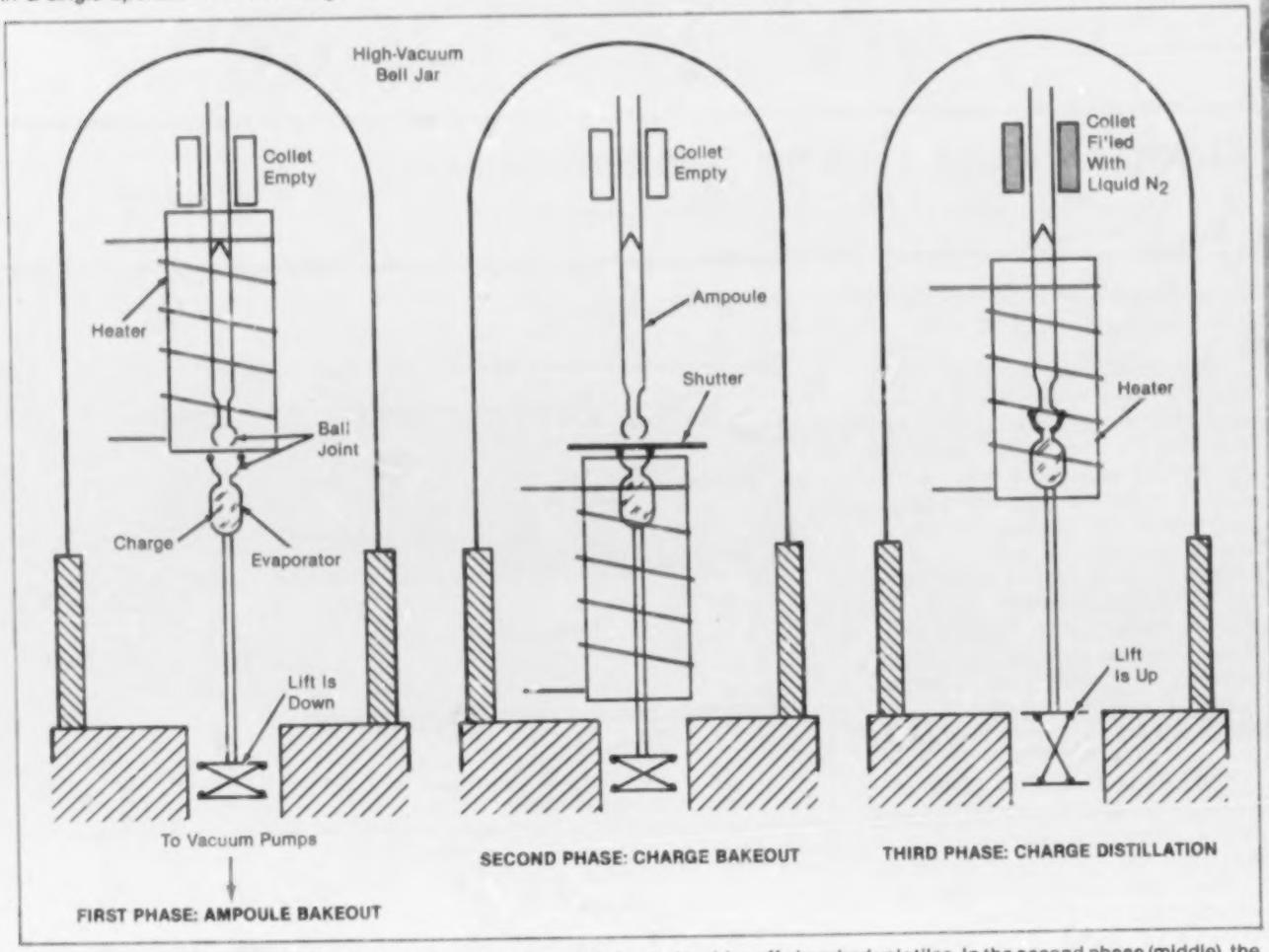
The **Foam Core** of the panel chars instead of burning. Decorative layers, speaker grills, and other details can be attached as on conventional panels.

Two-Step Vapor/Liquid/Solid Purification

One process approaches the theoretical limit of multiple zone refining and distillation.

Marshall Space Flight Center, Alabama

A vertical distillation system combines in a single operation the advantages of multiple zone refining with those of distillation. Developed specifically to load Bridgman-Stockbarger (vertical-solidification) growth ampoules with ultrapure



In the **First Phase of the Purification Process** (left), the ampoule is heated to drive off absorbed volatiles. In the second phase (middle), the evaporator is heated to drive off volatiles in the charge. In the third phase (right), the slowly descending heater causes distillation from the evaporator to the growing crystal in the ampoule.

tellurium and cadmium, this system, with suitable modifications, could serve as a material refiner.

In the new system (see figure), the raw charge is placed in an evaporator, from which it is distilled upward. The ampoule is connected to the evaporator by a dry, ground, vitreous-silica ball joint. The ampoule and evaporator are placed in a high-vacuum bell jar, which is pumped down to a pressure of 10^{-7} torr (10^{-5} N/m^2) or lower.

The evaporator has a long stem supported by a lift system controlled through a ferrofluidic rotary vacuum seal. The crystal-growth ampoule is also supported by a stem — a tube of the same inside and outside diameters as those of the ampoule body, so that it is a smooth continuation of the ampoule body. The stem extracts heat from the ampoule by thermal conduction. The stem is grasped by the spring fingers of a double-walled chuck cooled by liquid nitrogen.

The evaporator and the ampoule are surrounded by a movable heater 14 in. (36 cm) long that has a double winding of platinum wire 0.020 in. (0.05 cm) in diameter, 10 turns/in. (4 turns/cm) on the bottom 2 in. (5 cm) and 5 turns/in. (2 turns/cm) on the upper 12 in. (30 cm), wound on a vitreous-silica tube 1.1 in. (2.8 cm) in inside diameter. The heater is mounted on a recirculating-ball lead screw driven by a stepping motor that gives translation rates from 1 mm/h to 18mm/s, programmed by a preset indexer.

In the first phase of the operation, the evaporator is at its lowest position (with the ball joint open), the heater is positioned to heat only the ampoule, and the cold chuck is not supplied with liquid nitrogen. In this configuration, the ampoule is prebaked to about 400 °C in the vacuum to remove any adsorbed volatiles.

In the second phase, the heater is lowered to cover only the evaporator, and a shutter is placed in the open ball joint to mask off the ampoule. The charge in the evaporator is warmed until its vapor pressure is about 10^{-3} torr (10^{-1} N/m^2), so that moisture and other volatiles are driven off.

The third phase is initiated by removing the shutter, closing the ball joint, and raising the heater so that the top of the free volume in the ampoule is just inside the top of the heater. In this configuration, the charge in the evaporator is melted and heated until the vapor pressure is several torr (several hundred N/m^2), and the distillation process is started. As the distillation proceeds, the heater is moved downward, so that the top of the ampoule cools, thereby causing a crystal of purified material to start growing.

Because the crystal grows down from the top of the ampoule into the heater until it passes the melting-point isotherm, the solid material always has a drop of melt at the bottom end that is held up by surface tension. There is a segregation of impurities as the molten raw material is distilled to this drop and a second segregation as the material in the drop is solidified. When the growing drop reaches a certain size, it falls back into the evaporator, carrying with it impurities rejected in the solidification process. In this way, the solid growth face is constantly washed by fresh molten distillate. Thus the material is effectively purified by multiple zone refining and by distillation.

This work was done by Lawrence R. Holland of the University of Alabama, Huntsville, for **Marshall Space Flight Center**. *For further information, Circle 101 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

University of Alabama
Huntsville, AL 35899

Refer to MFS-26004, volume and number of this NASA Tech Briefs issue, and the page number.

Strong Adhesive Tape for Cold Environments

This strong tape remains sticky over a wide temperature range.

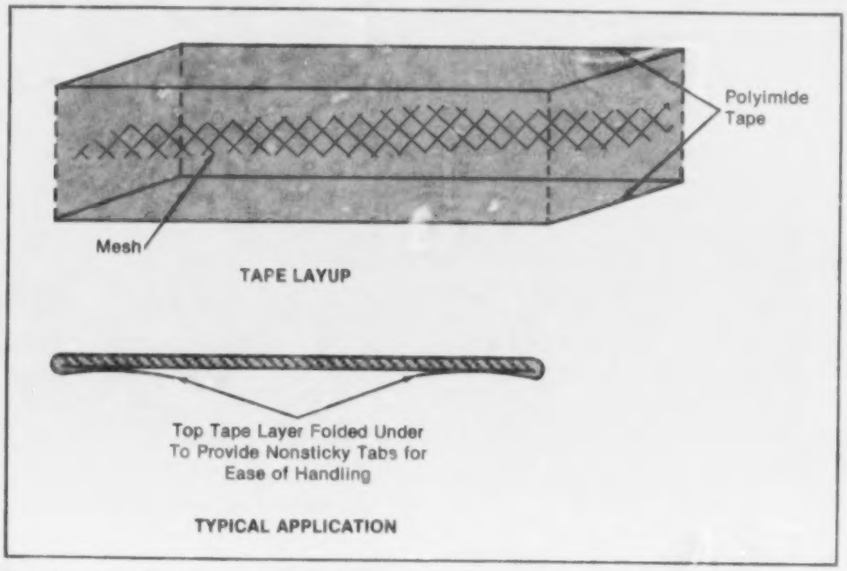
Lyndon B. Johnson Space Center, Houston, Texas

An improved tape devised for repairs in space may also find use on Earth in polar regions and in superconducting applications. The tape retains its adherence and strength at extreme temperatures, where conventional tapes would fail.

Experience on the Space Shuttle had shown that ordinary duct tape loses most, if not all, of its stickiness at the orbital temperatures. Kapton (or equivalent) polyimide tape, for example, maintained adequate adhesion but had to be layered for sufficient strength to resist inadvertent tearing by crewmembers. Multiple layers, however, make the tape stiffer.

The improved tape (see figure) consists of two layers of the polyimide tape with a reinforcing intermediate layer of thin, open-weave Kevlar (or equivalent) aromatic polyamid. Other mesh materials may also be suitable.

This work was done by Thomas G. Woods of McDonnell Douglas Corp. for **Johnson Space Center**. *No further documentation is available. MSC-20924*


Polyimide Tape
Mesh
TAPE LAYUP
Top Tape Layer Folded Under To Provide Nonsticky Tabs for Ease of Handling
TYPICAL APPLICATION

The Strong Tape for Low Temperatures consists of two layers of polyimide tape with a layer of reinforcing mesh.

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Circle Reader Action No. 371

Fuel Manifold Resists Embrittlement by Hydrogen

A completely-cast hydrogen-compatible alloy is preferable to protective plating.

Marshall Space Flight Center, Alabama

Parts exposed to high-pressure hydrogen can be made immune to hydrogen embrittlement if they are fabricated from a new alloy, Incoloy 903* (or equivalent). This material is strong and compatible with hydrogen at all temperatures and has been adapted for the outlet manifold of the Space Shuttle main combustion chamber.

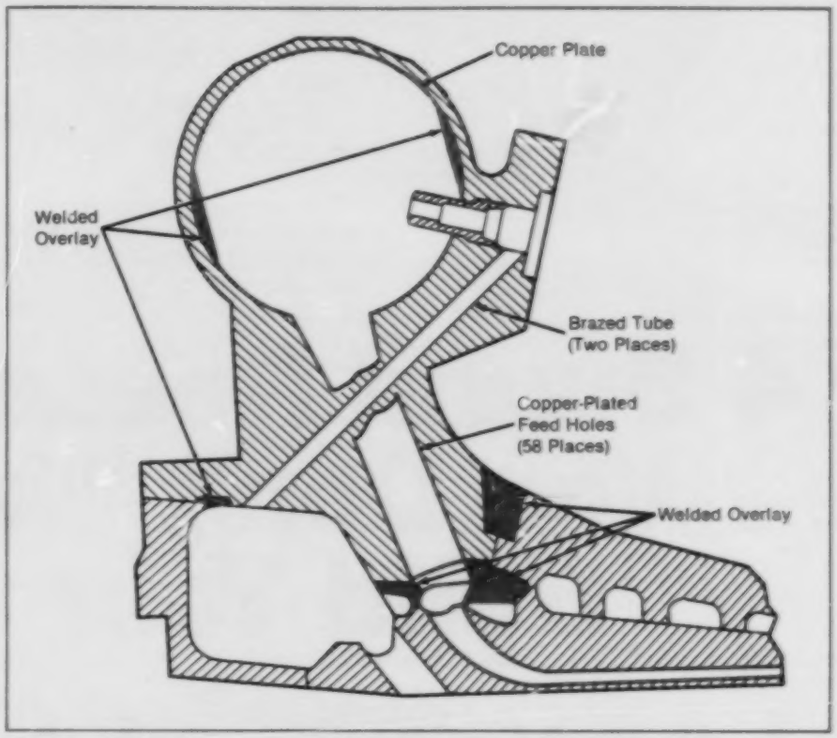
The manifold was formerly made of Inconel 718*, an alloy that is susceptible to hydrogen embrittlement at the engine operating temperatures. For protection, it had to be plated with copper on internal surfaces. In addition, overlays of Incoloy 903* had to be welded to it in certain areas, and a tube of the same alloy had to be brazed to it (see figure).

Substituting Incoloy 903* for the entire part eliminated the plating, welding, and brazing operations. As a result, the part can be made in less time and with fewer manufacturing flaws.

(*"Inconel" and "Incoloy" are registered trademarks of the INCO family of companies.)

This work was done by T. C. Adams of Rockwell International Corp. for **Marshall Space Flight Center.** *No further documentation is available.*

MFS-29089



The **Complexity of Plating, Welding, and Brazing** becomes unnecessary if a hydrogen-compatible alloy is used for the entire casting instead of merely as a protective overlay.

Iron/Phosphorus Alloys for Continuous Casting

Continuous casting becomes practicable because of reduced eutectic temperature.

NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental ferrous alloy has a melting point about 350 °C lower than that of conventional steels, making it possible to cast structural members and eliminating the need for hot rolling. The product has normal metal structure and good physical properties.

The casting process results in phosphorus steel — a strong ferrous alloy, rather than conventional iron/carbon-based steel. The alloy has important similarities to conventional steels: It includes a very hard phase of schreibersite (Fe_3P) similar to the cementite (Fe_3C) in conventional steel. Just as intimate mixtures of soft iron and hard cementite can be created by the cooling of conventional steels from the γ-phase region, so can intimate mixtures of soft iron and schreibersite be formed in phosphorus steels by the cooling from the liquid state. Furthermore, such elements as Mn, Ni, and Cr, which toughen conventional steels by forming finely divided hard carbides during the cooling from the γ region, also help to form finely divided hard phosphides on rapid cooling from a phosphorus-alloy melt.

The strongest Fe/P alloys contain 3 to 12 percent phosphorus by weight. The solidus (eutectic) temperature is 1,050 °C. In contrast, strong Fe/C alloys have a solidus temperature close to 1,400 °C. Materials that can contain the melt and extrude it are more readily available at the lower temperature than at the higher one.

The process could be used to make rails, beams, slabs, channels, and pipes. When fully developed, the process could be used where unrecyclable cooling water for hot rolling is not available. The process could be adopted by the developing countries to establish an indigenous product capability, without the high capital investment for rolling mills. More industrialized countries could make use of the readily available, lower grade ores without the beneficiation to remove phosphorus.

In the laboratory version of the process, steel bar stock is scalped to a diameter of 1 in. (2.5 cm) and cut to form a cylinder 1½ in. (3.81 cm) long. A hole 0.625 in. (1.59 cm) in diameter and 1 in. (2.5 cm) deep is bored in one end, leaving a cylindrical cup with a mass of about 110 g. A charge of phosphate is packed into the hole.

The cylinder is placed in an Alundum (or equivalent refractory alumina) crucible. Because the slag in the melt is highly corrosive to the alumina, the crucible is placed in another one on a layer of loosely packed alumina in a larger crucible. This provision ensures that the slag will not eat through the Alundum and pour the melt out of the crucible.

The cylinder and crucibles are placed in the coil of an induction furnace, and the radio-frequency power is gradually increased until the cylinder glows bright orange. At this point the reaction begins, and the iron, forming a eutectic with the phosphorus in the charge, melts at a lower temperature.

In a fully developed version of the process, a copper die would admit molten iron/phosphorus eutectic and extrude the solid alloy through its orifice. The orifice would be cooled internally, and recyclable water or a refrigerant could be used as the coolant.

Irregularly shaped parts could be made by sand casting the low-melting eutectic. The melt temperature would be low enough so that the sand could be selected from a variety of alternatives; for example, regolith or crushed dunitic rock.

This work was done by Eugene R. duFresne of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 55 on the TSP Request Card.*
NPO-16611

Polyether/Polyester Graft Copolymers

Higher solvent resistance is achieved along with lower melting temperature.

Langley Research Center, Hampton, Virginia

Aromatic polyethers, also known as polyphenylene oxides, are a class of polymeric materials that have been used in a wide variety of applications. However, they have certain deficiencies, including solubility in the common halocarbon and aromatic hydrocarbon types of paint thinners and removers. This sensitivity to solvents limits their use in structural articles that must be painted and repainted. They also have relatively high melting points, making them difficult to fabricate into finished parts. A new technique provides a method of preparing copolymers with polypivalolactone segments grafted onto a poly (2,6-dimethyl-phenylene oxide) backbone. This process makes strong materials with improved solvent resistance and crystalline, thermally-reversible crosslinks. These resulting graft copolymers are easier to fabricate into useful articles, including thin films, sheets, fibers, foams, laminates, and moldings.

The preparative process uses a modified form of the polyphenylene oxide — one that has various quantities of organic carboxylic acid groups substituted upon the base polyether (readily achieved by metallation of the polyether, followed by treatment with carbon dioxide). Some of the carboxylic acid groups are converted to tetrabutylammonium carboxylate salts or similar quaternary ammonium salts. The resulting carboxylate-salt-modified polyethers, dissolved in suitable solvents, are then reacted with varying amounts of pivalolactone, the graft polymerization of which is initiated by the carboxylate anions and proceeds rapidly to completion. Finally, the treatment of the grafted copolymer with a mineral acid converts the terminal tetrabutylammonium carboxylate salts to free carboxylic acid groups, completing the graft operation.

The polypivalolactone graft segments tend to crystallize very readily, a characteristic of polypivalolactone itself. When the graft segments from a number of polyether molecules crystallize together, the crystalline domains tie all the polymer molecules into a pseudocrosslinked material, which is much more resistant than the base polyphenylene oxide to halogenated and aromatic hydrocarbon solvents. Further, if the polypivalolactone grafts are sufficiently long, the entire graft copolymer melts as a consequence of the polypivalolactone crystallites melting, at a temperature lower than that associated with the base polyphenylene oxide.

The molecular weight of the polyether starting material can be varied to influence the properties of the graft copolymer. The degree of carboxylation, and thus the number of graft sites available, is another factor influencing the nature of the copolymer. The lengths of the grafted polypivalolactone segments, determined by the degree of carboxylation and the amount of polypivalolactone

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monomer that is polymerized, determine in turn the final balance of properties between those of the parent polyphenylene oxide and those of the highly crystalline polypivalolactone.

This work was done by Vernon L. Bell, Jr., N. J. Wakelyn, Diane M. Stoakley, and K. Mason Proctor of **Langley Research Center.** *For further information, Circle 59 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 27]. Refer to LAR-13447.

Low-Resistivity Zinc Selenide for Heterojunctions

Magnetron reactive sputtering would enable doping of this semiconductor.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed method of reactive sputtering combined with doping shows potential for yielding low-resistivity zinc selenide films. Zinc selenide is an attractive material for forming heterojunctions with such other semiconductor compounds as zinc phosphide, cadmium telluride, and gallium arsenide. Such semiconductor junctions are promising for future optoelectronic devices, including solar cells and electroluminescent displays. However, the resistivities of zinc selenide layers deposited by evaporation or chemical vapor deposition have been too high to form practical heterojunctions.

In the proposed technique, an indium- or gallium-doped zinc target would be sputtered in an atmosphere of hydrogen selenide and argon. Separate indium and zinc targets could also be sputtered simultaneously. The sputtered zinc would react with the hydrogen selenide to form zinc selenide, which would deposit as a film on a substrate of gallium arsenide or other semiconductor compound.

The rate of selenium incorporation in the zinc selenide layer would be closely adjusted by control of gas flow, sputtering power, and substrate temperature. This control would help to assure stoichiometric deposition and minimize zinc vacancies, which would otherwise neutralize the dopant and prevent it from reducing the resistivity.

Magnetron sputtering would be used. This sputtering technique would promote stoichiometric deposition of zinc and selenium. Because it confines secondary electrons to a region close to the cathode, magnetron sputtering would also prevent unintentional substrate heating. Thus, lower substrate temperatures would be possible, and radiant heat could be used to control substrate temperature independently as a process variable.

Sputtering proceeds at relatively high rates in magnetron systems because of the absence of heating by secondary electrons and because the long spiral paths of the discharge electrons cause ionization of argon at a much higher rate. The argon ions in turn sputter more zinc. Yet another advantage of magnetron sputtering is that the confinement of electrons by the magnetic field substantially reduces damage to the substrate and thus improves the electrical properties of the film.

Studies of deposition of other materials by reactive sputtering have already been made. These studies indicate that the key parameters affecting the composition, crystalline structure, and conductivity of zinc selenide will be:

- Discharge voltage,
- Discharge current,
- Substrate temperature,
- Partial pressure of hydrogen selenide,
- Total sputtering gas pressure, and
- Substrate bias voltage.

This work was done by Richard J. Stirn of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, Circle 58 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 27]. Refer to NPO-16475.

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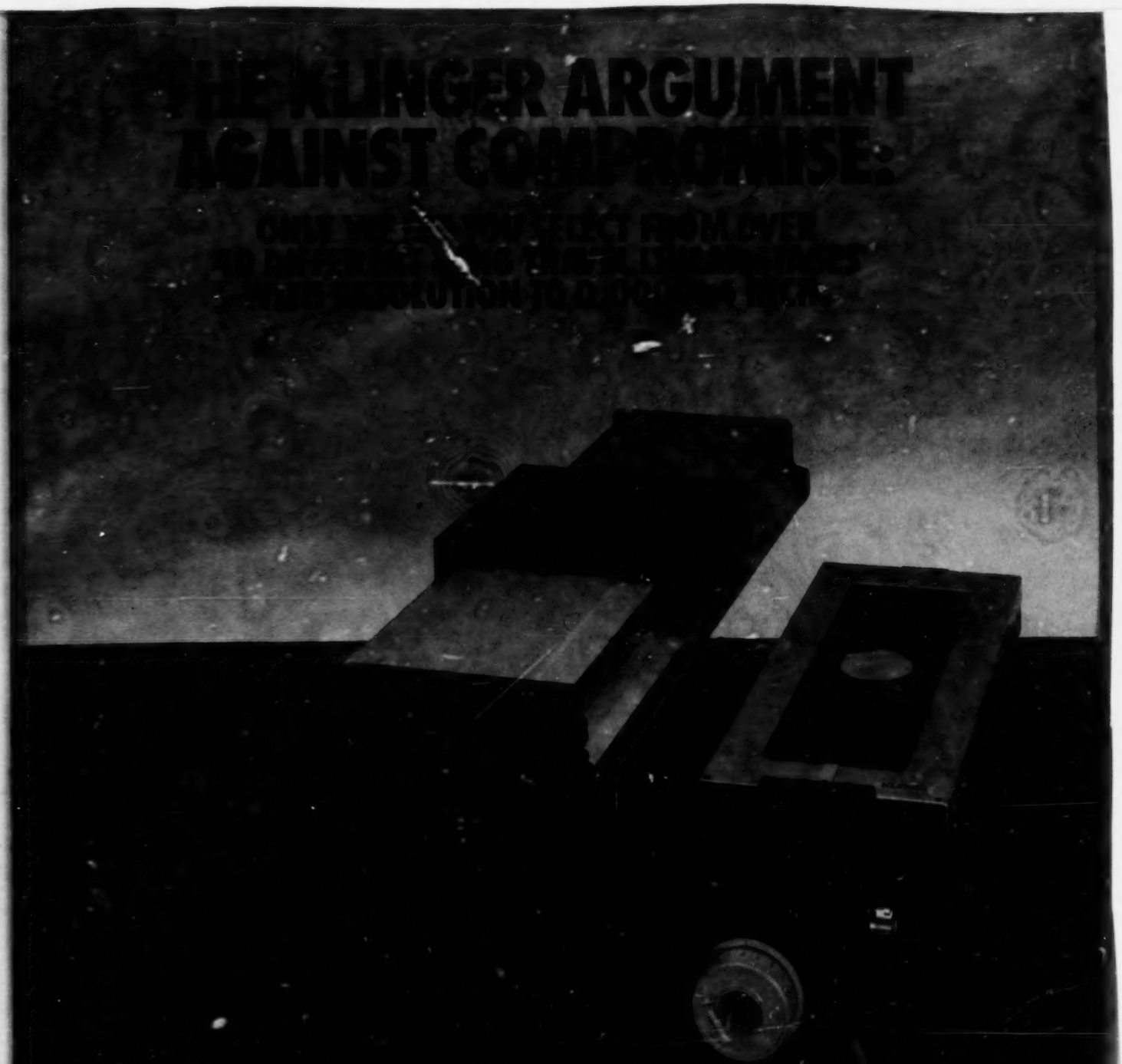

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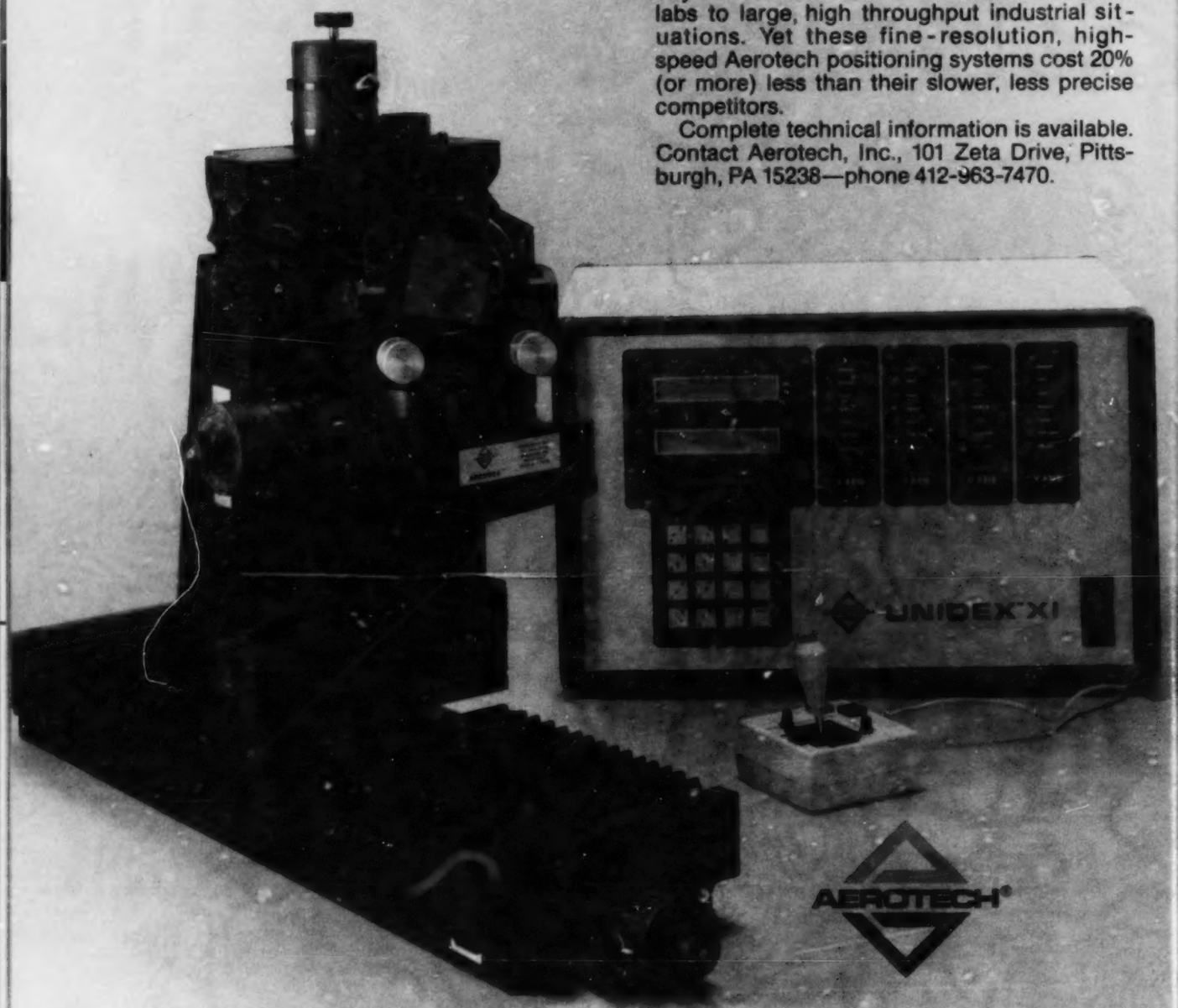

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Circle Reader Action No. 310

Chemical Characterization of Phenol/Formaldehyde Resins

Analytical procedures characterize resin composition and behavior before and during use.

A report discusses tests of commercial phenol/formaldehyde resins to establish relationships among the composition before use, the behavior during curing, and the strength after curing. The resin is used in carbon/carbon laminates. In the curing process, two molecules of a phenol are joined together in a sequence of reactions involving a molecule of formaldehyde. In the last step of the sequence, a molecule of water is released. The sequence repeats until one of the ingredients is used up, leaving a solidified thermoset plastic. Among the issues to be resolved are the number and relative abundances of ingredients, the presence of certain chemical groups, the heat-producing ability of the resin, and the range of molecular weights present.

The laboratory methods used to characterize the resins, reactions, and cured products include the following:

- Physical tests that reveal the relative quantities of volatiles and resin and the amount of resin flow during a cure at low pressure;
- Mechanical tests of the flexural strength, flexural modulus, and shear strength; and
- Instrumental analyses that distinguish among the compositions and chemical behaviors of different resin formulations.

The report presents the data from these tests in graphs and tables. The following were the results from the investigation:

- In order of decreasing utility and information yield, the instrumental analyses are liquid or gel-permeation chromatography; infrared spectroscopy; and differential scanning calorimetry, thermomechanical analysis, or thermogravimetric analysis.
- The resins are mixtures of commercially available phenols and coreactants.
- The phenols are typically substituted in the metaposition.
- The coreactants dissociate to produce compounds containing carbonyl groups.
- Phenol is one of the ingredients.
- Resins with low phenol content may be inadequate.
- The reaction between the metasubstituted phenols and the coreactant proceeds stepwise rather than smoothly.
- Resin mixtures are fairly reactive and start to react at low temperatures.

The report also presents the following:

- High-pressure liquid chromatography and gel-permeation chromatography should be adopted as the main instrumental analyses.
- Incoming resins and prepregs should continue to be examined by chemical and mechanical methods to build up the data base.
- The resin mixtures should be separated into components, which should be subsequently identified as specific compounds.

This work was done by Thomas H. Brayden of LTV Aerospace and Defense Co. for **Johnson Space Center.** *For further information, Circle 79 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center *[see page 27].* *Refer to MSC-21055.*

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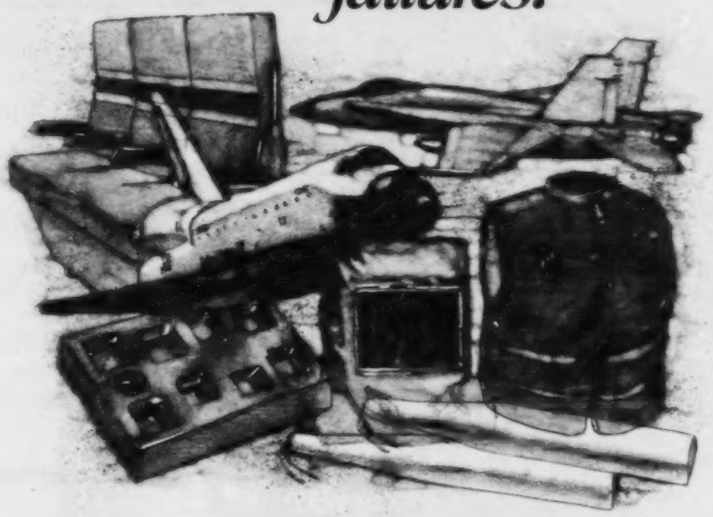

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Computer Programs

60 Updated Thermal-Radiation Program

61 NASA Test File

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For additional information on any programs described in this issue of *Tech Briefs*, circle the appropriate number on the TSP card at the back of the publication. If you don't find a program in this issue that meets your needs, you can call COSMIC directly at (404) 542-3265 and request a review of programs in your area of interest. There is no charge for this information review.

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Physical Sciences

Updated Thermal-Radiation Program

Used with other thermal-analysis programs, this program calculates the radiation components.

The Thermal Radiation Analyzer System, TRASYS II, is a computer-software system with generalized capability to solve the radiation-related aspects of thermal-analysis problems. When TRASYS II is used in conjunction with a generalized thermal-analysis program, such as the Systems Improved Numerical Differencing Analyzer (SINDA) program, any thermal problem that can be expressed in terms of a lumped-parameter R-C thermal network can be solved.

TRASYS II provides for the calculation of internode radiation-interchange data and for the calculation of incident- and absorbed-heat rate data originating from environmental radiant-heat sources. Data of both types are provided by TRASYS II in a format directly usable by such thermal-analyzer programs as SINDA (available from COSMIC).

TRASYS II consists of two major components: the preprocessor and the processor library. One primary feature of TRASYS II is that it allows users to write their own executive, or driver, programs, which organize and direct the library routines toward solving each specific problem in the most expeditious manner. The preprocessor first reads and converts the user's geometry-input data into the form used by the processor-library routines. Next, the preprocessor accepts the user's driving logic, written in the TRASYS II-modified FORTRAN language, that directs the user-provided and processor-library routines in the solution of the problem.

The processor library consists of FORTRAN routines that perform the functions commonly needed by the user to solve the thermal-radiation problems. In many cases, the user has a choice of solution techniques to perform the same function. As previously mentioned, users may provide their own routines where desirable. In particular, the user may write output routines to provide for an interface between TRASYS II and any thermal-analyzer program using the R-C network concept.

Input to the TRASYS II program consists of EDIT/CONTROL data and MODEL data. The EDIT/CONTROL data do not participate in the definition of the thermal-radiation problem, but provide for basic program control and for the definition of the mathematical model of the thermal-radiation problem. The MODEL data include surface-geometry data, documentation data, nodal data, block-coordinate-system data, form-factor data, operations data (the user's driver logic), and the user-supplied subroutines. TRASYS II currently allows problems with as many as 1,000 nodes and time-variable problem geometry. The edit capability allows for the easy modification of complex thermal-radiation problem models.

Output from TRASYS II consists of two basic types of data: internode-radiation-interchange data, and incident- and absorbed-heat rate data. A plot package provides for the plotting of input geometry, orbit data (for on-station spacecraft problems), the two types of data described above, and any other data generated by the user's driver logic.

The DEC VAX version of TRASYS II is written in FORTRAN IV for batch execution (only the plotting driver program is interactive) and has been implemented on a DEC VAX 11/780 computer under VMS. The UNIVAC version of TRASYS II is written in FORTRAN V and Assembler for batch execution and has been implemented on a UNIVAC 1100 series computer under EXEC 8 with a central-memory requirement of 40K to 115K of 36-bit words. TRASYS II requires the DISSPLA plot software package for graphics output and drives Tektronix terminals. The TRASYS II system was last updated in 1985.

This program was written by Robert A. Vogt of **Johnson Space Center**. *For further information, Circle 28 on the TSP Request Card.*
MSC-20448 and MSC21030

Mathematics & Information Sciences

NASA Test File

Comparisons among different computer-aided design systems are facilitated.

The Test File is a data file containing computer-aided design (CAD) data formatted according to the National Bureau of Standards Initial Graphic Exchange Specification (IGES). This file was created for the purpose of conducting NASA tests to determine to what extent dissimilar CAD systems can exchange data using the IGES standard formats and IGES translators.

The IGES Test File is used to test IGES translators by converting the IGES format data to and from the native internal format of the CAD system. The file contains 28 different IGES entities, which were chosen because they define the geometric, annotation, and display-formatting information that is important in CAD information transfer. The documentation contains a procedure for using the file to test IGES translators, along with sample output of the scaled, rotated, and translated entities. It has been verified by an independent company that the file does indeed conform to Version 2.0 of the IGES standard.

These data are in ASCII code and are machine-independent. The file was created in 1985.

This program was written by Scott Gordon of **Goddard Space Flight Center**. *For further information, Circle 65 on the TSP Request Card.*
GSC-12988

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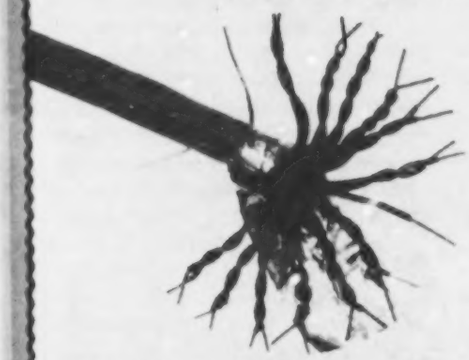

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Mechanics

Hardware, Techniques, and Processes

62 **Measuring Hole Elongation in Bolted Joints**
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Measuring Hole Elongation in Bolted Joints

The measurement does not affect joint parameters.

Langley Research Center, Hampton, Virginia

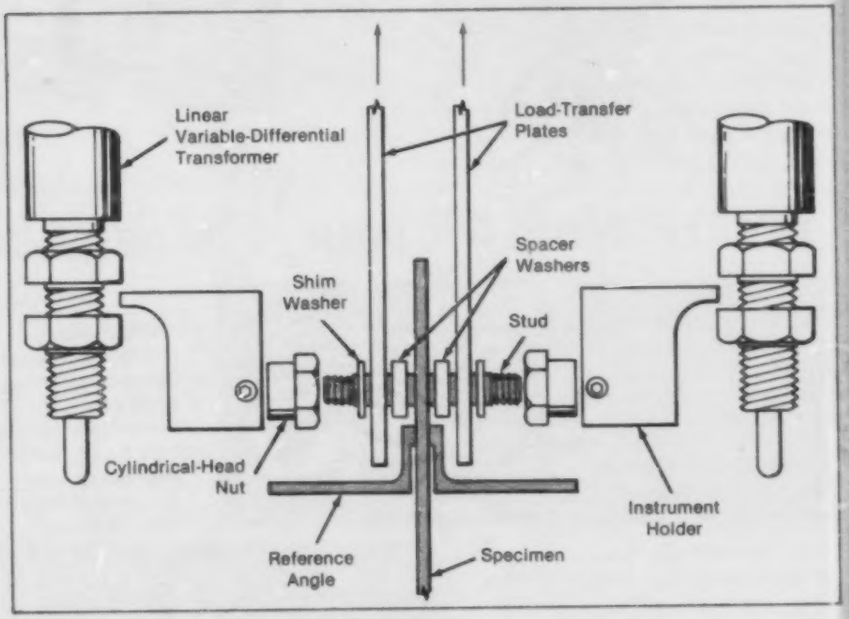
The verification of analytical and strength-prediction methods for bolted composite joints is based generally on data obtained experimentally from double-lap-joint specimens. In mechanically fastened joints, the stresses are maximal at the fastener holes. The ability to measure accurately hole elongations without affecting the joint parameters would provide a better understanding of the elastic and plastic behavior of the joint material leading to failure. The effective determination of the failure mechanisms in mechanically fastened joints is required for the design of more-efficient, lightweight composite joints.

A double-lap-joint-testing assembly for measuring hole elongation without affecting joint parameters is shown in the figure. The bodies of the linear variable-differential transformers (LVDT's) are rigidly attached to the stud. The movable cores of the LVDT's are in contact with the reference angles, which are securely bonded to the test specimen below the spacer washers. The center of the reference-angle area bonded to the specimen is one reference point, and the top of the stud in contact with the hole is the other reference point.

As the hole elongates under tensile loading, the distance between the stud and the reference angle increases because of the stress concentrations around the hole. The cores of the LVDT's move with the reference angles, and the change in distance between the two reference points is reflected in the output voltages of the LVDT's.

With increasing load, displacements caused by bending and bearing stresses within the stud will be measured along with the hole elongations. However, these stud displacements would, in many cases, be negligible with high-strength, hardened-steel studs. In cases where stud displacements must be taken into account, the magnitudes of elastic displacements could be analytically determined and subtracted from the measured displacements, yielding only the hole elongations.

This measurement technique offers a direct comparison between the displacements occurring at each outer-hole surface since the measuring instruments are equidistant from the specimen surfaces, and the reference angles are mounted opposite each other. Within the elastic limit of the specimen material, specimen bending or unequal loading through the load-transfer plates can be detected by comparing the displacement-versus-load responses. The technique is suitable for different bolt diameters, washer sizes



This **Double-Lap-Joint-Testing Assembly** is used to measure the elongations of holes in specimens.

(clamping areas), clamping forces (bolt torque), and joint materials, and for some multifastener arrangements.

This work was done by Gregory R. Wichorek of **Langley Research Center.** *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 27]. Refer to LAR-13453.

Redundant Pyrotechnic/Manual Release Mechanism

When all else fails, manual intervention is possible.

Marshall Space Flight Center, Alabama

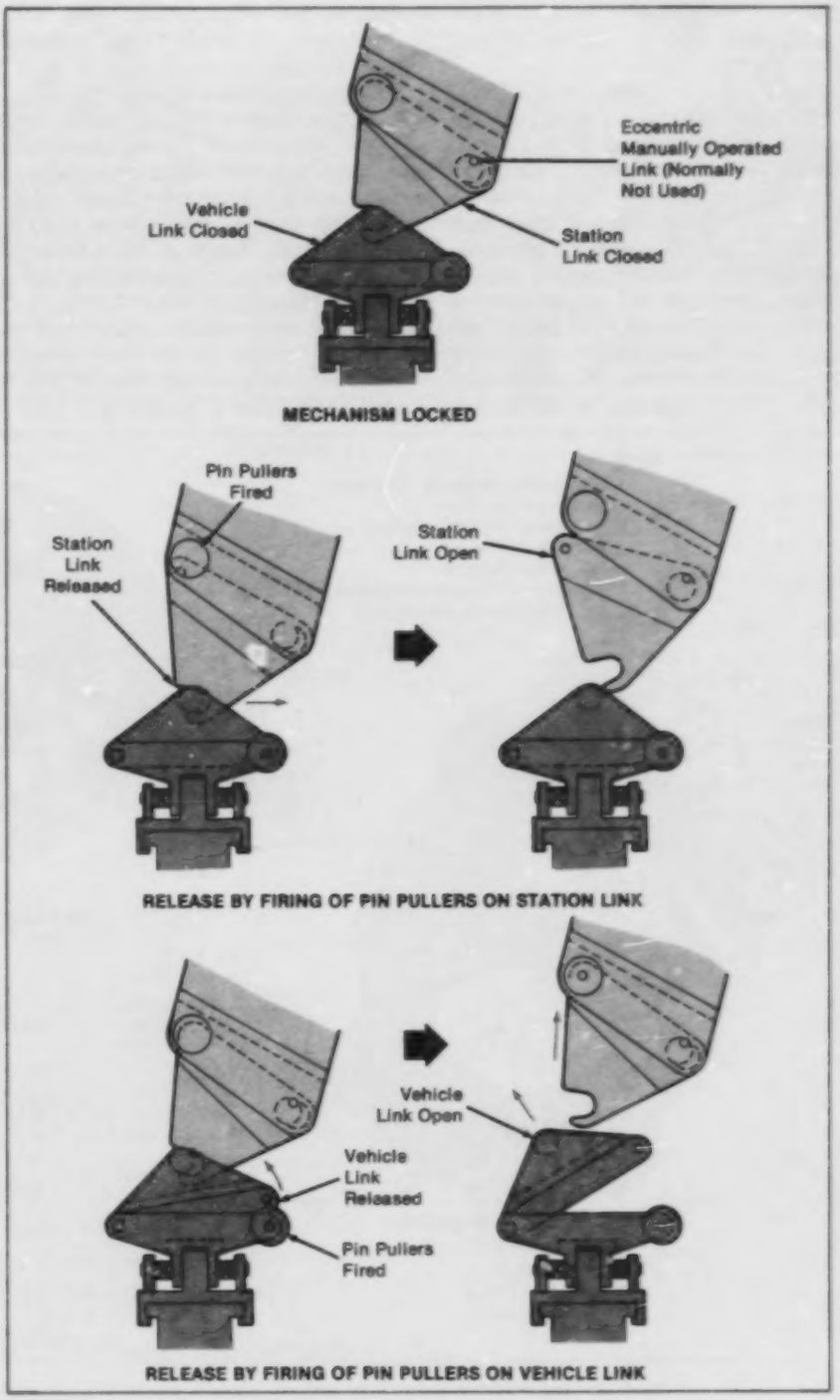
A release mechanism is designed to be operable by remote control even if many of its components fail. In the unlikely event that it does become inoperable, it can still be actuated manually.

The mechanism was developed for releasing the Space Station and its tether line from the Space Shuttle in orbit. There are two such mechanisms, each having two releasable links: one on the Space Station side and one on the Space Shuttle side (see figure). The actuation of either link on either mechanism will separate the two systems. Such a mechanism may be useful on Earth for the emergency release of modular structures or vehicle sections.

First, a pair of dual-initiator pyrotechnic pin pullers on the station side is fired by an electric signal from the station so that the open-faced link disengages from its cam roller. If one of the initiators or pullers in a pair should fail, the link will still disengage. If both sets of initiators and both pin pullers fail, the pair of pin pullers on the vehicle side would be fired by a signal from the vehicle. Again, if one of the initiators or pin pullers should fail, the link would still open.

Since there are eight pyrotechnic initiators altogether, the probability that no release will occur is very small indeed. But if it should, or if a power failure should prevent firing signals from being sent, a crew member, working outside would turn the cam roller on the station link by 180° and thereby open the link.

This work was done by Gilbert M. Kyrias of Martin Marietta Corp. for **Marshall Space Flight Center.** *For further information, Circle 99 on the TSP Request Card.*
MFS-28096


Eccentric Manually Operated Link (Normally Not Used)
Vehicle Link Closed
Station Link Closed
MECHANISM LOCKED
Pin Pullers Fired
Station Link Released
Station Link Open
RELEASE BY FIRING OF PIN PULLERS ON STATION LINK
Vehicle Link Open
Vehicle Link Released
Pin Pullers Fired
RELEASE BY FIRING OF PIN PULLERS ON VEHICLE LINK

Two Modes of Separation—on the station side of the mechanism (top) and on the vehicle side (bottom) ensure highly fail-safe operation. If only one of the eight pyrotechnic initiators in the pin pullers fires, the links of the mechanism will separate.

One-Piece Force-Transducer Body

A rugged unit is designed to operate in severe environment.

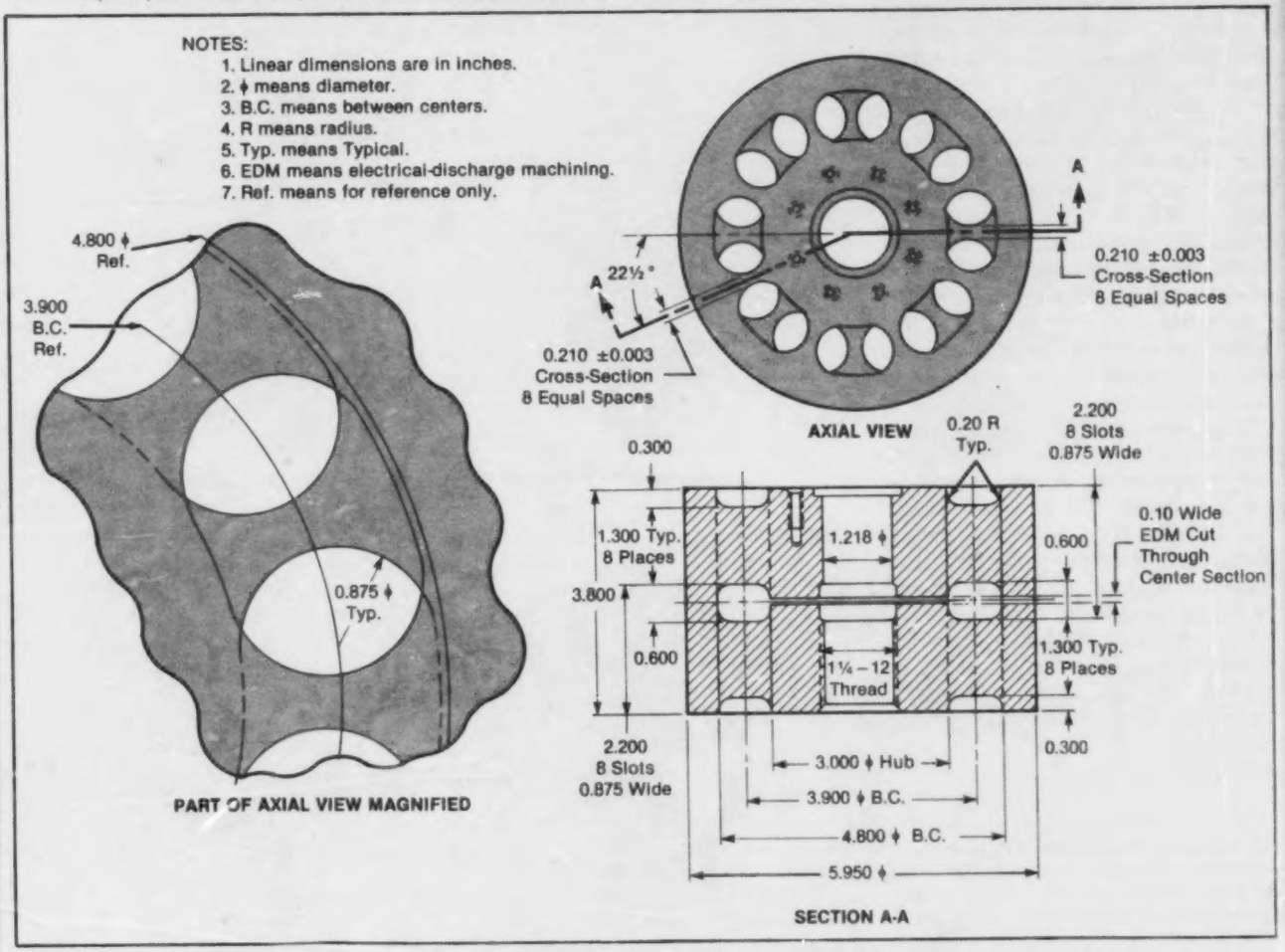
Marshall Space Flight Center, Alabama

A force-transducer body is designed for the measurement of loads on specimens tested in hydrogen gas at temperatures up to 2,000 °F (1,090 °C). The body has a symmetrical radial-shear-beam configuration and is machined in one piece from bar stock.

Shear-beam load cells are in general use. Some commercially available units are of the rectangular S-bend beam design, which is asymmetrical about the axis of load application. This asymmetry is considered undesirable. Another type of commercial unit is circularly symmetrical but is manufactured in several pieces, with spokes radiating from a central hub to an outer hub through a bolt circle. The sensing structure is bolted through the bolt circle to a second circular adapter plate that incorporates a central thread. A central loading thread is thus available at opposite ends of the load-cell assembly.

The symmetrical commercial units have several disadvantages. They are unreliable in the severe testing environment because of the large number of highly stressed joints between the parts. Assembly requires the painstaking concentric alignment of the two parts that contain the central thread. Mating parts can slip relatively to each other under load. The relative motion of parts can cause fretting fatigue of the joint surfaces under cyclic reversed loading. The slippage of bolted joints can cause hysteresis in the measurements. Even if properly designed, bolted joints exhibit asymmetry because they have different spring stiffnesses in tension and compression.

The new symmetrical load-cell body (see figure) is rugged. It has all of the stiffness, strength, accuracy, and low overall height of a conventional two-piece radial shear beam. However, because it is made in only one piece — as opposed to two major pieces and at least eight fasteners in the conventional design — it is both more reliable and less expensive. The concentricity between the opposite central threads is machined in, eliminating the need of alignment in assembly. The new configuration has no inherent asymmetry between tension and compression. Finally, the new unit is easier to seal against the environment because there are no bolted joints, each of which would otherwise have to be sealed individually.



The **Symmetrical Force-Transducer Body** is machined in this configuration from a piece of bar stock.

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This work was done by Richard A. Meyer of MTS Systems Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-28140

Shape Determination for Large Static Structures

Parameter and shape estimates are updated from new measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

A set of algorithms generates updated estimates of state vectors representing the static deflections or other responses of large structures and of physical parameters of structural components (for example, the elastic moduli of beams or ribs in a truss of many such elements). The algorithms result from a generalization of the Kalman statistical-filter technique. A degree of computational economy is achieved in that there are mathematical elements common to the estimates of the parameters and of the responses. This is an advance over prior filter methods, which have treated the estimation of the two types of quantities in different ways.

The mathematical model of a structure in this analysis is a set of elliptic partial differential equations that may be interconnected. The model includes the parameters, which, in principle, can be determined through measurements of the structural responses to applied loads. Because the model and the response and load measurements are contaminated by random errors, a statistical analysis is needed to find the best estimate of the parameters. The measurement and model errors are represented in the model equations as weighted white-noise components.

The parameter estimation (see figure) involves a Newton-Raphson iteration process. The iteration begins with the current parameter estimate based on previous measurements and calculations. The square-root filter processes the external load inputs and measured deflections to obtain filtered measurements and filtered estimates of the deflections predicted theoretically from the load inputs and model. The square-root-filter output is the set of errors obtained by subtraction of the filtered predictions from the filtered measurements.

The gradient/Hessian synthesis block forms the function-space gradient of a likelihood functional and the approximate Hessian, which is the matrix of second derivatives of the likelihood functional. The likelihood functional takes an extreme value (usually a minimum) at the best estimate of the parameters. Using the gradient and the approximate Hessian, the Newton-Raphson iteration block calculates the updated parameter set, which is the next set that brings the likelihood functional closer to the extremum.

The state-estimation algorithms were derived primarily for the determination of the shapes of large parabolic antenna reflectors. These algorithms are based on two sets of measurements; namely, the measured structural deflections of the first model plus measurements of the electromagnetic far field, which is affected by the deflections. The first model is thus expanded to include additional equations relating the field measurements, the deflection (state or response)

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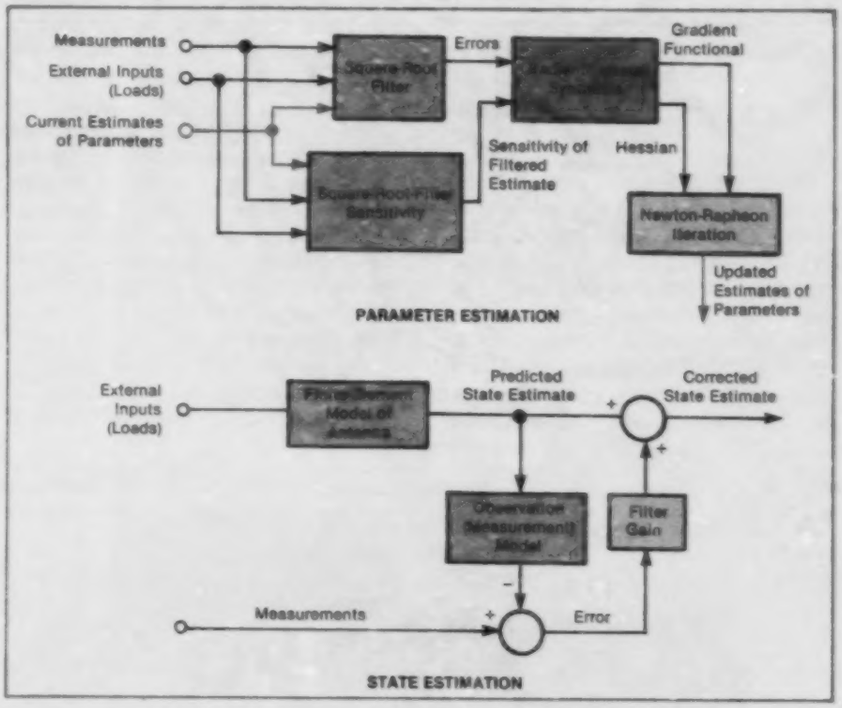

The Parameter and State Estimations involve statistical structural analysis, statistical electromagnetic-field analysis, filtering, measurement modeling, and iterative prediction/correction procedures. The estimating algorithms result from generalizations of Kalman statistical-filter theory.

estimate, and the additional noise that enters through the field measurements.

The problem is solved in two prediction/correction stages similar to that described above for the parameters. In the first stage, a predicted state estimate is generated by a finite-element model of the structure. This estimate is entered in the model of an electro-optical deflection sensor to predict the sensor output. The actual and predicted sensor data are then compared; the differences are processed through a three-dimensional spatially-distributed Kalman filter to obtain correction terms, which are used to further correct the deflection estimate. The second prediction/correction stage performs similar operations, using the field model and field measurements.

This work was done by Guillermo Rodriguez and Robert E. Scheid, Jr., of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 89 on the TSP Request Card.*
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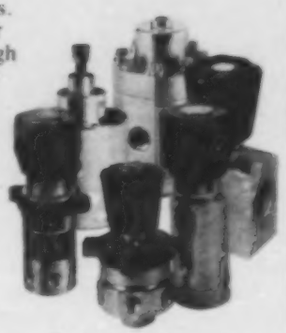

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Measuring Atmospheric Turbulence With Lidar

Laser Doppler measurements promise to give reliably accurate indications of wind speed and turbulence.

A report compares two kinds of measurements of wind and turbulence: those from instruments aboard an aircraft and those from ground-based Doppler measurements by laser ranging equipment (lidar). The data on wind fields, turbulence intensities, and turbulence spectra from the two sources agreed well. The report concludes that lidar is potentially a reliable and accurate instrument for sensing atmospheric turbulence remotely.

The lidar was a variably-pulsed carbon dioxide laser system. During this study, the pulse intervals were 2 μs long. The lidar measured the radial wind velocities in each of a succession of 300-m-long conical frusta defined by the diverging lidar beam and the succession of pulse intervals.

The aircraft was flown in circular paths to capture the lidar beam during a conical scan. The lidar aim was then fixed at 6° above the horizon and the aircraft flown along a 4° glide slope. The aircraft measurements were converted to radial wind-gust velocities in 300-m intervals corresponding to the lidar range intervals.

Turbulence intensities and spectra were calculated from the fluctuations in the radial component (the component along the lidar beam) of wind velocity with time. Attempts to measure turbulence intensities directly by lidar from the second moment or Doppler-frequency spectral width were disappointing. The second moment could be resolved only at very low altitudes. Moreover, turbulence intensities estimated from the spectral-width data were an order of magnitude higher than values measured from the aircraft.

An interesting boundary-layer condition occurred during the measurements: Winds blew in one direction above 600 m above mean sea level and in the opposite direction below this altitude. Both the aircraft and the lidar measurements clearly identified the condition and showed identical trends, giving added credence to the remote-sensing possibilities of lidar.

This work was done by Walter Frost and H. B. Kuang of FWG Associates, Inc., for **Marshall Space Flight Center**. *Futher information may be found in NASA CR-170976 [N84-17574/NSP], "Doppler Lidar Signal and Turbulence Study."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 106 on the TSP Request Card.
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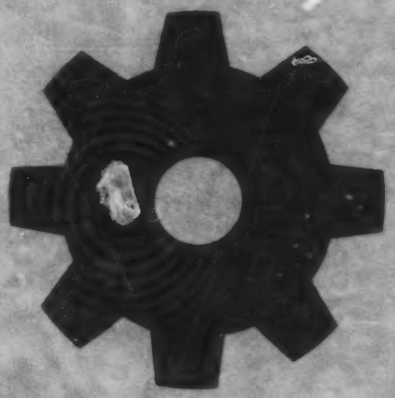

Hardware, Techniques, and Processes

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81 Synopses of Magneto-hydrodynamic Power Generation

Circulation-Control Variable-Pitch Propeller

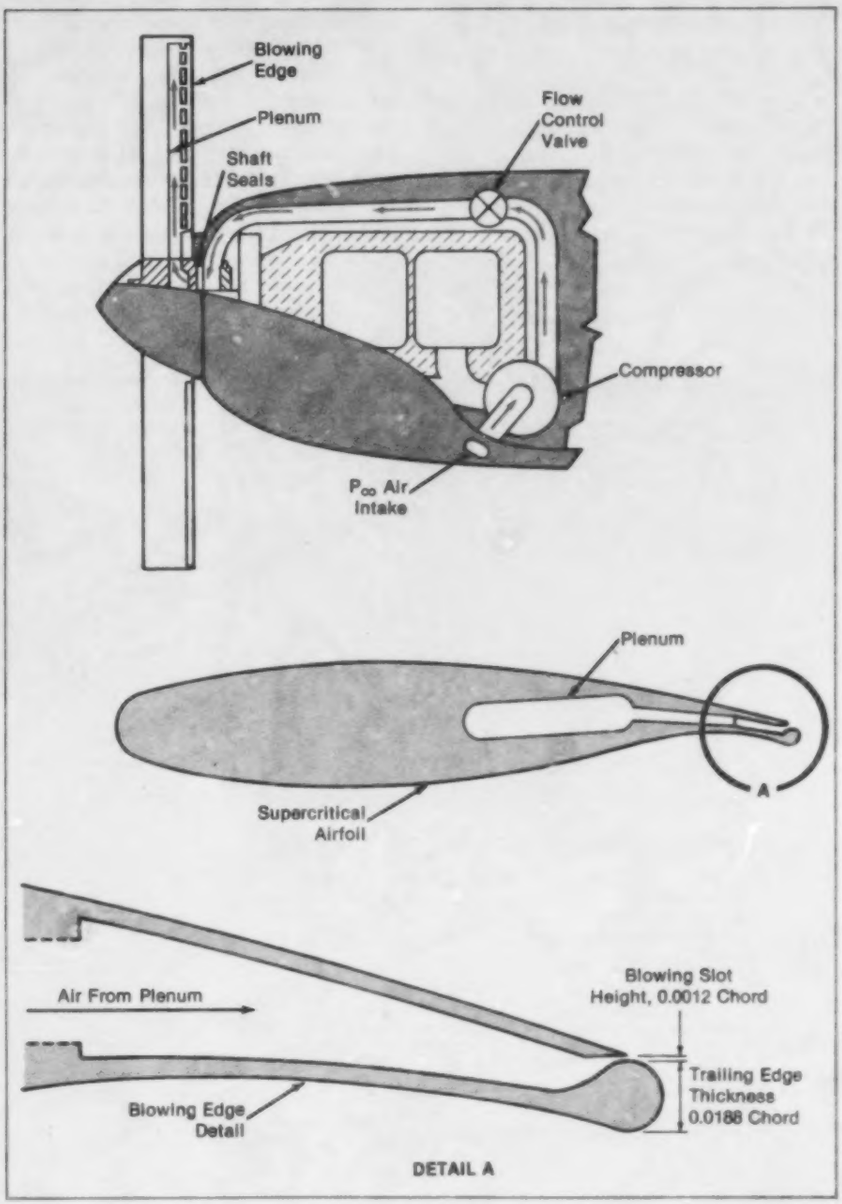
Blown aerodynamics concept would improve reliability and reduce costs.

Langley Research Center, Hampton, Virginia

A variable-pitch propeller based on the circulation-control airfoil concept has no moving parts other than those needed for propeller rotation. When substituted for a conventional variable-pitch propeller airfoil, it would lower manufacturing costs, reduce maintenance, and improve reliability.

In previous designs to vary pitch for different flight regimes (such as takeoff and cruise), the individual propeller blades are rotated about their span axes by hydraulic or electric motors. These approaches require precise, moving machine elements, increasing costs, maintenance requirements, and opportunities for failure.

The circulation-control airfoil concept (see figure), under development for a



Circulation-Control Variable-Pitch Propeller has a large lift value at very moderate blowing coefficients.

number of years, involves blowing a tangential stream of air from a thin upper-surface slot over the airfoil rounded trailing edge. The jet sheet remains attached to and turns around the trailing edge, thus controlling the circulation around the airfoil. In the current design, this principle controls the effective pitch of the propeller.

Air for the blowing slot is supplied by an engine-driven air pump through a labyrinth seal at the propeller hub. By controlling the flow of air to the propeller, the effective pitch of the propeller may be changed in flight.

Since large changes in angle-of-attack have little effect on coefficient-of-lift, a propeller using this airfoil would tend to be self-compensating for changes in aircraft forward speed, even without an adjustment of the air supply. However, an automatic system for sensing engine speed and controlling the airflow to maintain constant speed over a range of power settings could be easily incorporated into the design. This would be done preferably by fluidic control, for maximum reliability.

With the circulation-control variable-pitch propeller, the effective pitch of the propeller could be varied over a wide range, simply by controlling the flow of air to the blowing slot. In small aircraft, it would improve takeoff performance and increase fuel economy at little or no additional cost.

This work was done by H. Douglas Garner of **Langley Research Center.** *Further information may be found in NASA CR-165968 [N85-29959/NSP], "Circulation Control Propellers for General Aviation, Including a Basic Computer Program."*

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Pitch Control for Helicopter Rotors

Blade pitches are controlled in synchronism.

Ames Research Center, Moffett Field, California

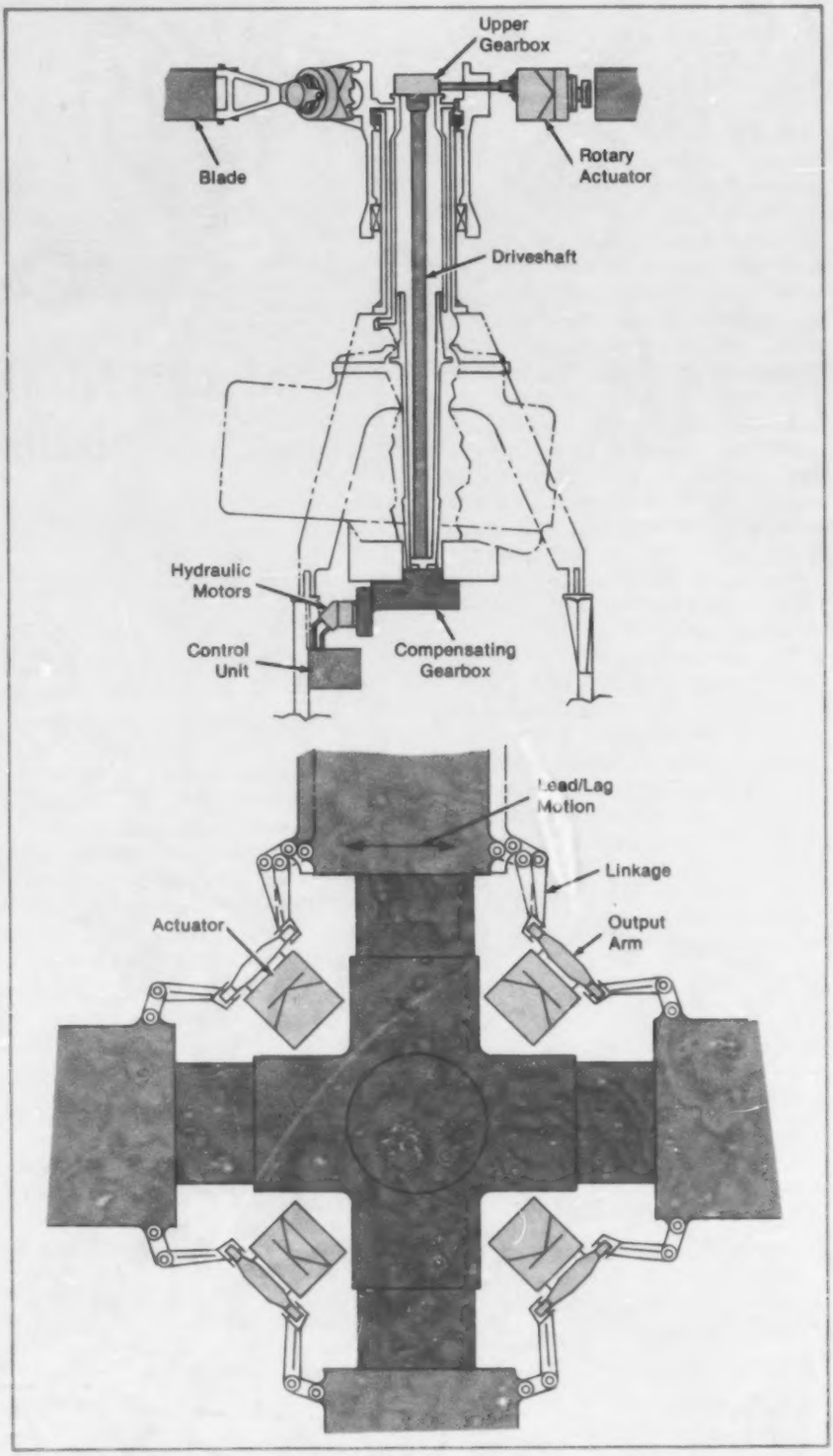
A pitch controller for helicopter rotors uses hub-mounted actuators located symmetrically between rotor blades. The new controller is designed for X-wing rotors that require collective pitch control; that is, the pitch of all blades must be changed by the same amount. The collective control allows the rotor to be trimmed during a variety of flight regimes, in particular during hovering and fixed-wing flight.

If a conventional pitch controller were used on an X-wing rotor, the load paths through the control linkages would be long and would add considerable weight if they were to provide satisfactory stiffness. In addition, a conventional controller can be used only if the blade roots are firmly supported against vertical deflection, and, with such support, it would be difficult for the conventional controller to allow lead/lag motion of the blades without coupling the motion to the blade pitch motion. Furthermore, it would be difficult to stiffen the open blade section for attachment of a horn arm.

The new controller, in contrast, has a short load path and is therefore stiff without excess weight. Its linkage permits large lead/lag motion of the blade without changing the blade pitch; the linkage also restrains vertical shear forces on the blade. Moreover, all linkages and drives are redundant: A single failure cannot cause catastrophic loss of control.

The new controller consists of four hub-mounted rotary actuators, each on an axis midway between a pair of blades, linkages that connect the output arms of the actuators to the root ends of the blades, and a drive system that synchronizes the operation of the four actuators (see figure). Each actuator arm can rotate through an angle of ±30°, which results in a pitch change of ±10° at the blade. Each linkage keeps its blade in the rotorplane while allowing in-plane lead/lag motion of ±1.75 inches (4.4 centimeters).

A hydraulic power unit drives the actuators. The unit is mounted on the airframe under the main-rotor-transmission gearbox. The unit includes two independent hydraulic motors and a control section. The combined output passes through a compensating gearbox to dual torque shafts inside the rotor shaft. The compensating gearbox removes the ef-



Atop the Main Rotor Driveshaft but isolated from its motion, four actuators control and synchronize the pitch of helicopter rotor blades.

fect of rotor rotation from the drive shafts. The shaft distributes torque to the actuators via an upper gearbox and four individual shafts, one connected to each actuator.

The pitch controller is operated by a redundant command signal, which controls flow of hydraulic fluid to the motors. Each motor is supplied by a separate hydraulic system. The malfunction of a motor or failure of its hydraulic supply causes a brake to be applied to the motor; the remaining motor then operates the actuators at half speed.

The actuator mounting is also redundant. One of the two pitch-control linkages on any one blade may fail, and the remaining linkage will continue to control the blade. Similarly, if any one actuator input shaft fails, the adjacent blades will be controlled from the neighboring actuators, the inoperative actuator being backdriven.

This work was done by P. Jeffery and G. Luecke of United Technologies Corp. for **Ames Research Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 27]. Refer to ARC-11517.

Algorithm for Fuel-Conservative Airplane Descents

Pilots use a small programmable calculator to plan descents.

Langley Research Center, Hampton, Virginia

The Federal Aviation Administration is implementing an automated, time-based metering form of air-traffic control (ATC) with profile-descent procedures for arrivals into the terminal area. These measures provide fuel savings by matching the arrival of airplanes to the airport acceptance rate through time-control computations and by allowing the pilot to descend at his discretion from the cruise altitude to a designated metering-fix altitude in an idle-thrust clean configuration (with landing gear up, flaps zero, and speed brakes retracted). An airborne descent algorithm was developed at Langley Research Center to be compatible with time-based metering and profile-descent procedures and was designed to improve the accuracy of delivering an airplane during a fuel-efficient descent to the metering fix at a time designated by the ATC system.

The simple, airborne flight-management descent algorithm (see Figure 1) was programmed into a small calculator (see Figure 2) for use with a McDonnell Douglas DC-10-10 airplane. In a time-metered mode, the airborne algorithm computes the specific mach number, airspeed, and point for the pilot to begin the descent to arrive at a metering fix at a predetermined airspeed, altitude, and time assigned by ATC. In the nonmetered mode, the algorithm computes the point to begin the descent based on the mach and airspeed descent schedule entered into the calculator by the pilot.

Flight tests were conducted on routine airline flights into various major airports.

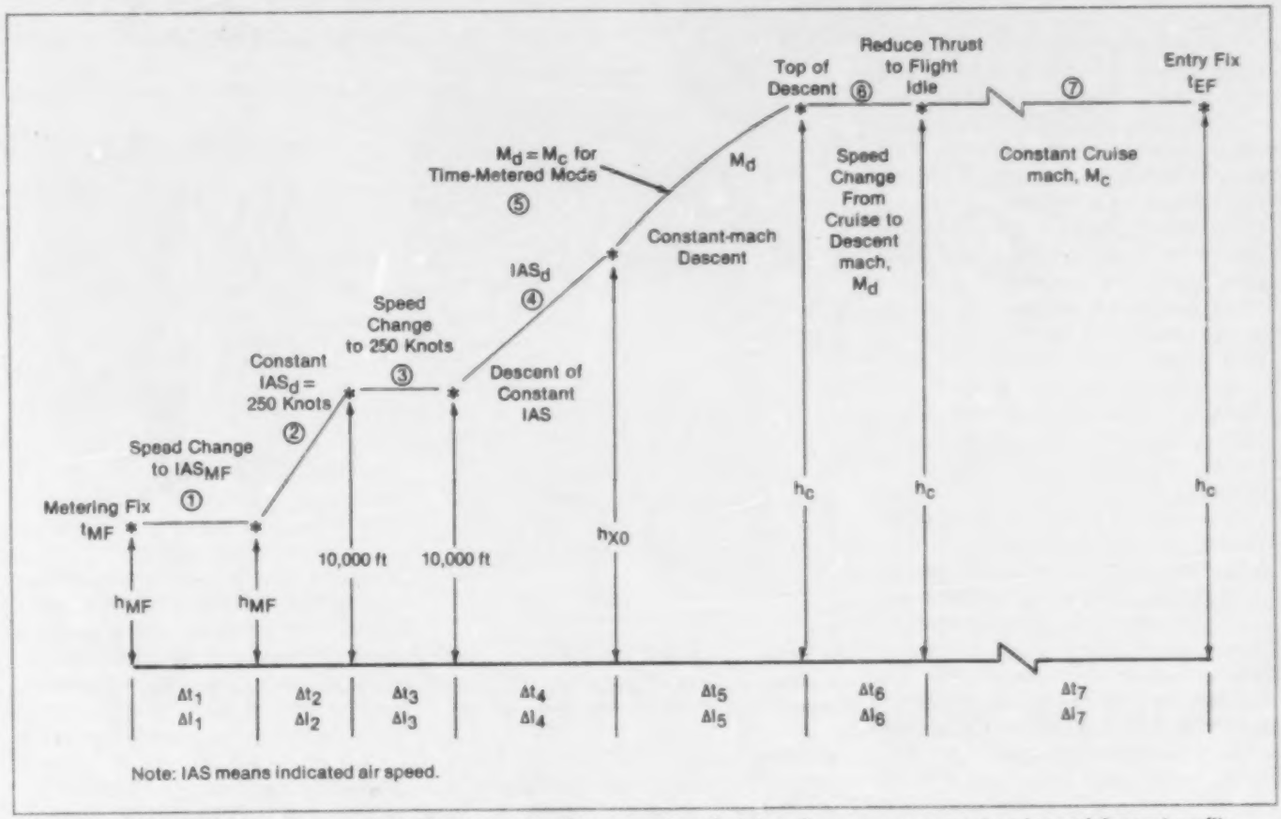


Figure 1. The **Flight-Management Algorithm** computes the parameters that describe a seven-segment cruise-and-descent profile.

The data obtained indicated that the time and distance to descend could be satisfactorily predicted with the use of relatively simple equations and modeling of airplane performance characteristics. The flight data also have shown that the descent profile could be satisfactorily flown with open-loop guidance provided by conventional cockpit mach and airspeed indicators; however, the pilot technique used to fly the descent can affect the accuracy of crossing the metering fix at the desired time.

The pilots who participated in the flight tests reported that the calculator was easy to use and did not interfere with normal flight duties. They felt that the open-loop guidance provided by the calculator would be of most value during the descents at nonstandard speeds or during time-metered operations.

This work was done by Charles E. Knox and Dan D. Vicroy of **Langley Research Center** *and David A. Simmon of United Airlines, Inc. Further information may be found in:*

NASA TM-85642 [N83-25707/NSP], "Description of the Computations and Pilot Procedures for Planning Fuel-Conservative Descents with a Small Programmable Calculator,"

NASA TM-85275 [N84-29871/NSP], "User's Manual for a Fuel-Conservative Descent Planning Algorithm Implemented on a Small Programmable Calculator," and

NASA TP-2393 [N85-26705/NSP], "Planning Fuel-Conservative Descents in an Airplane Environment Using a Small Programmable Calculator."

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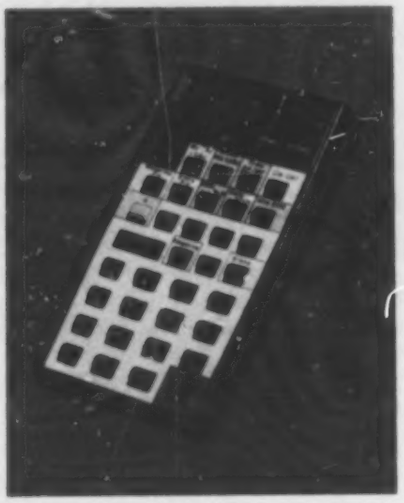


Figure 2. **The Hand-Held Programmable Calculator** does not interfere with normal flight duties.

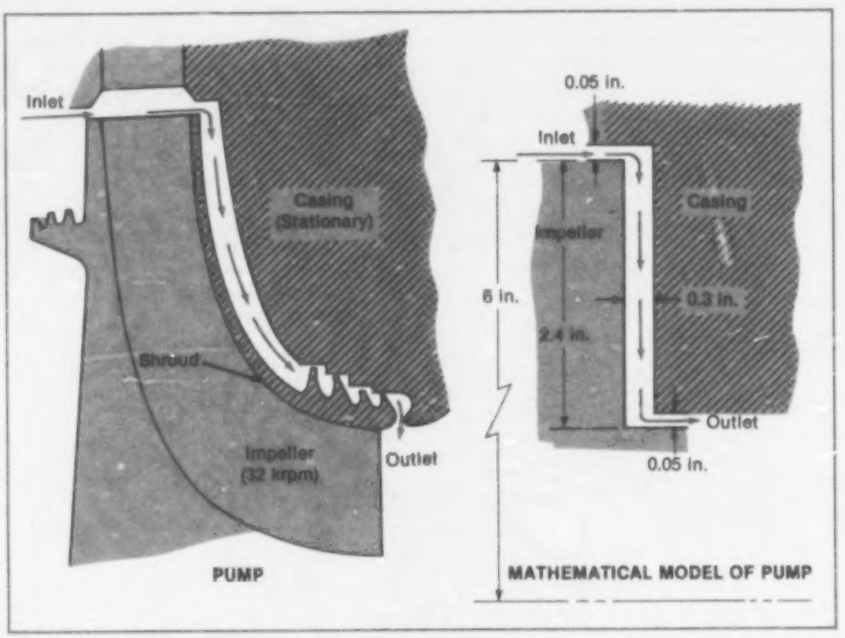
Analysis of Leakage Flows in Turbomachinery

Navier-Stokes calculations predict leakage flow in a high-pressure fuel pump.

Marshall Space Flight Center, Alabama

The accurate calculation of internal turbomachinery flow dynamics can help spot possible failure modes and can establish the coupling between cyclic loading and structural dynamics. Such an analysis has been applied to leakage flow between the impeller shroud and the casing in a high-pressure fuel pump used in the Space Shuttle main engine (see figure). The underlying approach should also be useful in analyzing two-and quasi-three-dimensional leakage flows in other turbomachinery components.

An existing computer program was modified to simulate this leakage flow. It uses a quasi-three-dimensional Navier-Stokes formulation. It solves the partial differential flow equations by an iterative under-relaxation procedure based on an integral control-volume analysis with hybrid finite differencing and staggered grids. A 63- by 81-node nonuniform mesh was used in the analysis to provide sufficient resolution in the regions of greatest flow variations, which are the inlet, the exit, and the regions near the surfaces of the impeller and casing. This mesh also reduces the effects of numerical diffusion. The high-Reynolds-number form of the k-ε model of turbulence (supplemented with wall functions near the walls) is used to close the equations for the turbulence and mean-flow fields. The computational technique has been tested extensively on other complex turbulent flows.



Leakage-Flow Geometries are shown for both the actual pump and for the simplified model used in the leakage-flow analysis.

The vector diagram in the figure depicts the flow for an arbitrary set of conditions. The vectors indicate the radial and axial components of fluid velocity at

selected mesh points. Calculations were done for a variety of mass-flow rates and other conditions believed to bracket those expected in the actual pump. The numerical results indicate that significant radial and axial motion takes place only in the boundary layers in the immediate vicinity of the surfaces of the impeller and casing. In addition to the net leakage flow, there is a circulation consisting of outward flow along the impeller and inward flow along the casing. The portion of the fluid not in the boundary layers has small axial and radial velocities but rotates at a nearly uniform angular velocity that ranges from 60 to 78 percent of that of the impeller shaft.

This work was done by Munir M. Sindir of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 23 on the TSP Request Card.*
MFS-29152

Balancing High-Speed Rotors at Low Speed

Flexible balancing reduces vibrations at operating speeds.

Marshall Space Flight Center, Alabama

High-speed rotors in turbomachines can be dynamically balanced at a fraction of the operating rotor speed. The method results in a precisely balanced rotor at, say, 30,000 r/min even though the rotor weight distribution has been adjusted at a much lower speed — for example, 2,000 r/min.

Unlike other low-speed, rigid-body balancing, the new method takes into account that the rotor is flexible rather than rigid. The method is based on balancing "windows" — combinations of speed and support flexibility at which two conditions occur simultaneously. The system behaves flexibly (that is, distinct balance planes can be discerned along the shaft), and the system response to the addition of balance weights is large enough to measure reliably.

The method consists of the following four steps:

1. The balance planes are selected. They must be in axial planes where weight can be added or removed at any circumferential location. They must not be at vibrational nodes at the speeds of interest, and they must be active at the low speeds at which balancing will be performed.
2. The speeds are determined at which there is separation among the planes; that is, at which a weight in each plane would cause a different rotor response.
3. The speeds are determined at which the rotor response is measurable with sufficient accuracy.
4. Finally, the influence-coefficient balancing is performed at speeds where the rotor is both flexible and responsive.

The low-speed flexible balancing method was evaluated empirically with a rotor-dynamic test rig. The rig was assembled with supports that simulated those of an oxygen turbopump. For this arrangement, a low-speed balancing window was predicted at 8,000 r/min. The rig was balanced at this and other speeds. The balancing resulted in smooth operation of up to 24,000 r/min, and the two critical speeds below it were traversed without excessive vibration (see figure).

By way of comparison, a high-speed balance was done on the test rig. The

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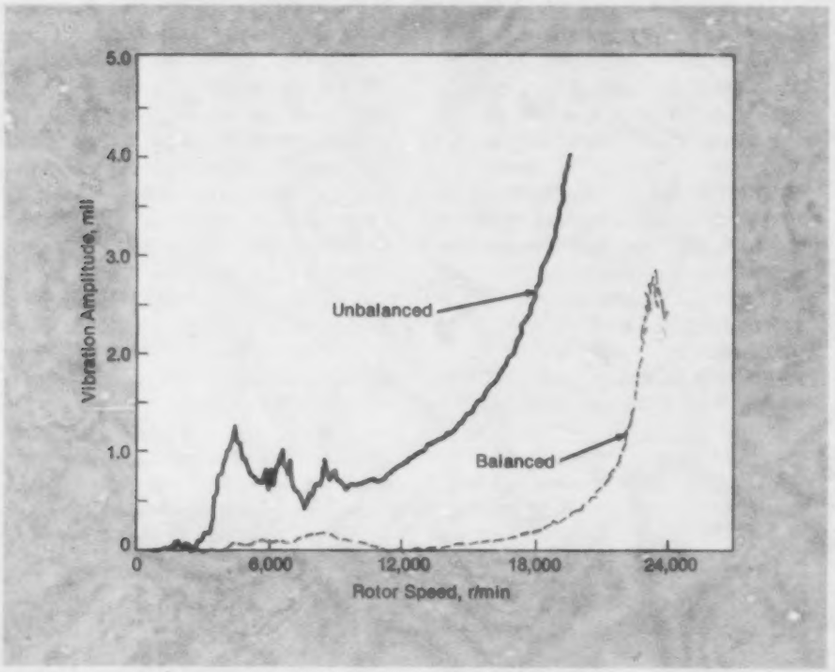

quality of balance was approximately the same as it was for the low-speed, flexible balance. A low-speed, rigid-body balance was also done. This method produced little reduction in vibration amplitude, and the maximum speed was limited to 20,000 r/min.

This work was done by J. Giordano and E. Zorzi of Mechanical Technology, Inc., for **Marshall Space Flight Center**. *For further information, Circle 21 on the TSP Request Card.*
MFS-28130

Before- and After-Balancing Curves show that flexible-body balancing at 8,000 r/min ensures smooth rotation up to at least 24,000 r/min. The vibration peaks at the critical speeds and the sharp rise of vibrations at intermediate speeds are eliminated.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Flexible-Rotor Balancing Demonstration

Treating the rotor as a flexible body at low rotational speeds allows balancing without high-speed tests.

A report describes a method for balancing high-speed rotors at relatively low speeds and discusses a demonstration of the method on a laboratory test rig. The method ensures that a rotor can be brought up to speeds well over 20,000 r/min smoothly, without excessive vibration amplitude at critical speeds or at the operating speed. The method was developed for balancing the rotors of turbopumps in the Space Shuttle main engine; these pumps are difficult or impossible to balance at their full operating speed [see "Balancing High-Speed Rotors at Low Speed" (MFS-28130), in this issue of *NASA Tech Briefs*].

The report presents the theory of low-speed flexible balancing and contrasts the new method with full-speed balancing and with low-speed balancing in which the rotor is regarded as a rigid body rather than as a flexible one. It describes the rotordynamic test rig used to demonstrate the method, analyzes the dynamics of the demonstration, and discusses the results. An appendix gives a sample computer output for test-rig critical speed.

The objective of low-speed flexible balancing is to add or remove weights from a rotor/bearing system to minimize unwanted vibrations. The weight distributions predicted by this method should produce vibrations, at the measurement planes, equal and opposite to those due to rotor imbalance. The weights are predicted on the basis of measurements at low speeds in such a way that vibrations are minimized at the balancing speeds and at the intended operating speeds.

The report concludes that low-speed flexible-rotor balancing is a viable technology and that the quality of balance achieved with low-speed flexible-rotor balancing is roughly equivalent to that of high-speed flexible balancing. The report also concludes that rigid-body balancing at low speed is unacceptable for high-speed operation.

This work was done by J. Giordano and E. Zorzi of Mechanical Technology, Inc., for **Marshall Space Flight Center.** *To obtain a copy of the report, "HPOTP Low-Speed Flexible Rotor Balancing — Phase I Final Report," Circle 20 on the TSP Request Card.*
MFS-28132

Liquid-Hydrogen Polygeneration System

The system utilizes coal as an alternate chemical feedstock.

A polygeneration system would use existing technology in an integrated process to produce liquid hydrogen space-vehicle propellant and such important secondary products as gaseous nitrogen, electrical energy, and thermal energy. The system can make the commercial launch services economically attractive against future competition. The system could lower the expected cost of liquid hydrogen by utilizing relatively cheap coal feedstocks and by reducing the electrical costs associated with producing liquid hydrogen.

The integrated process includes a coal-gasification and gas-cleanup system, a combined-cycle power-generation system, a hydrogen-production/liquefaction system, and an air-separation system. A clean, medium-BTU gas is produced by the coal-gasification system and is delivered to the power-generation system and the hydrogen-production/liquefaction system.

Steam, produced in the coal-gasification process, is delivered to a steam turbine combined with a gas turbine, to which the gas is delivered, to generate electrical and thermal power in a combined-cycle power-generation process.

Steam from the coal-gasification process is also delivered to a shift-conversion unit in the hydrogen-production system to increase the hydrogen content of the gas before liquefication.

The air-separation system produces oxygen and gaseous nitrogen. The oxygen is used in the coal-gasification process, and the gaseous nitrogen is delivered for storage to the launch site, where it is used as an inert gas to purge critical environments. The gaseous nitrogen is also used in the hydrogen-production system, where the nitrogen is liquefied and used to refrigerate the hydrogen.

This work was done by P. A. Minderman, G. P. Gutkowski, L. Manfredi, J. V. King, and F. S. Howard of **Kennedy Space Center**. *To obtain a copy of the report, "Liquid Hydrogen Polygeneration System and Process," Circle 53 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Kennedy Space Center [see page 27]. Refer to KSC-11304.

Synopsis of Magnetohydrodynamic Power Generation

A summary reviews the state of development.

A concise summary of magnetohydrodynamic (MHD) theory, history, and future trends is presented in a report. Worldwide research on MHD is covered, and selected data from key research projects are included. A magnetohydrodynamic generator produces electric current by passing a fluid at high speed through a strong magnetic field. The fluid may be an ionized gas, a plasma, or a liquid metal. Although much work remains to be done in this field, magnetohydrodynamic generators offer the potential for high efficiency, low power cost, and cleaner emissions.

Operating at about 3,000 K, a typical magnetohydrodynamic generator presents major materials problems. For example, the channel and the electrodes are subject to erosion and to damage by heat. In addition, reducing heat loss and decreasing the cost of the magnet are major concerns.

The fact that magnetohydrodynamic generators produce direct current rather than alternating current can be a hindrance, since dc-to-ac inverters are expensive. However, many industries — metal processing, for example — need dc.

The report notes that despite the disadvantages, magnetohydrodynamic power generation appears to be one of the best ways to utilize domestic coal reserves. Over a period of time, the high initial costs would be absorbed by lower production costs. Equally important, a coal-fired magnetohydrodynamic powerplant would pollute the environment far less than does a conventional steam plant:

- It would reject only half the heat of a conventional plant.
- Particulate pollution would be removed by the alkali-metal seed-recovery setup that would be a necessary part of an ionic magnetohydrodynamic system.
- Nitrous oxide and sulfur dioxide could readily be removed.

This work was done by James L. Smith of **Marshall Space Flight Center**. *Further information may be found in NASA TP-2331 [N84-25458/NSP], "Magnetohydrodynamic Power Generation."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. The report is also available on microfiche at no charge. To obtain a microfiche copy, Circle 54 on the TSP Request Card. MFS-27073

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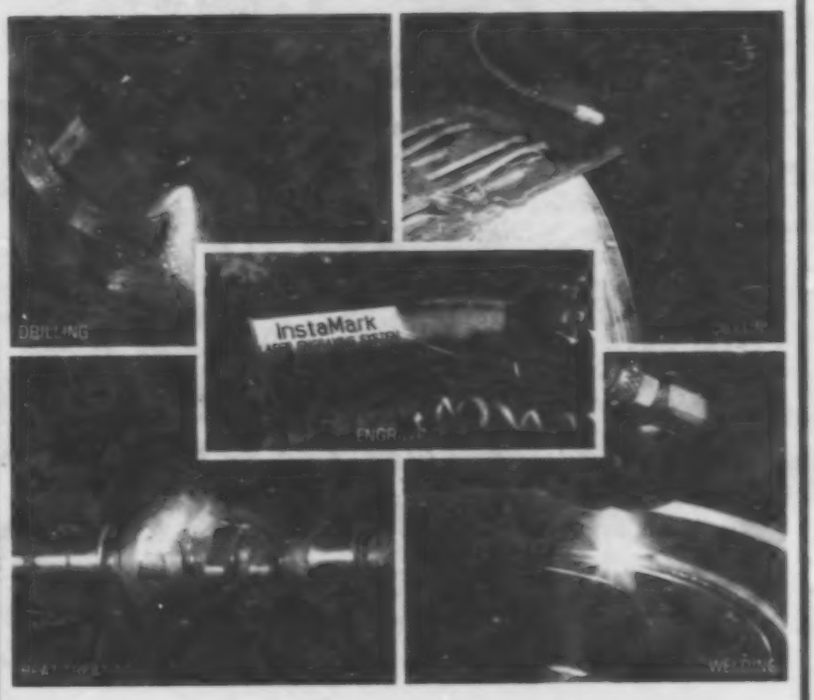

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Fabrication Technology

Hardware, Techniques, and Processes

82 Lightweight, Nesting Struts
83 Producing Refractory Microballoons
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85 Storing Chemicals in Packed Spheres
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87 Covering Cavities by Electrodeposition

Books and Reports

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Lightweight, Nesting Struts

Hollow cones are easily assembled to form trusses.

Marshall Space Flight Center, Alabama

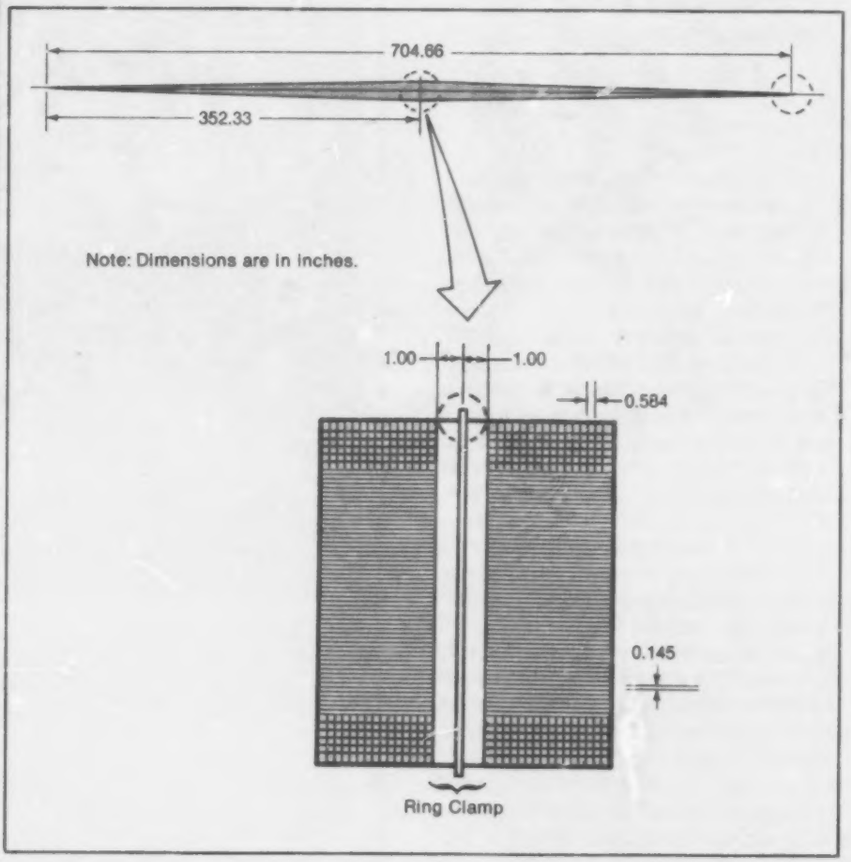
Struts made of graphite-fiber-reinforced epoxy resin are tapered for stiffness and for compact nesting for transportation. They nevertheless are fabricated with a constant load-bearing cross section. The struts were developed for building large truss structures in space. They can be readily carried to the construction site in the Space Shuttle and quickly assembled. They may also be useful on Earth in small structures where great strength is not required.

Each strut is 9 m long and 0.305 m in diameter at its large end, tapering to 0.025 m in diameter at its small end. In each strut, 260 graphite/epoxy fiber bundles run the length of the long, narrow, hollow cone. A single bundle is wrapped in a helix on the outside of the cone to stabilize the longitudinal fibers.

A pair of struts is joined by a ring clamp at the large-diameter end (see figure). The end fittings are bonded to the struts during manufacturing so that the double-strut assembly can be easily inserted in the truss as a structural member. A completed pair of struts with its fittings has a mass of 5.7 kg.

This work was done by Richard M. Gates and Kenneth P. Hernley of The Boeing Co. for **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 27]. Refer to MFS-28116.



A **Ring Clamp Holds Struts** together as a pair. Fibers extend longitudinally and helically along each tapered member.

Producing Refractory Microballoons

Metals, ceramics, and glasses are just some of the possible raw materials.

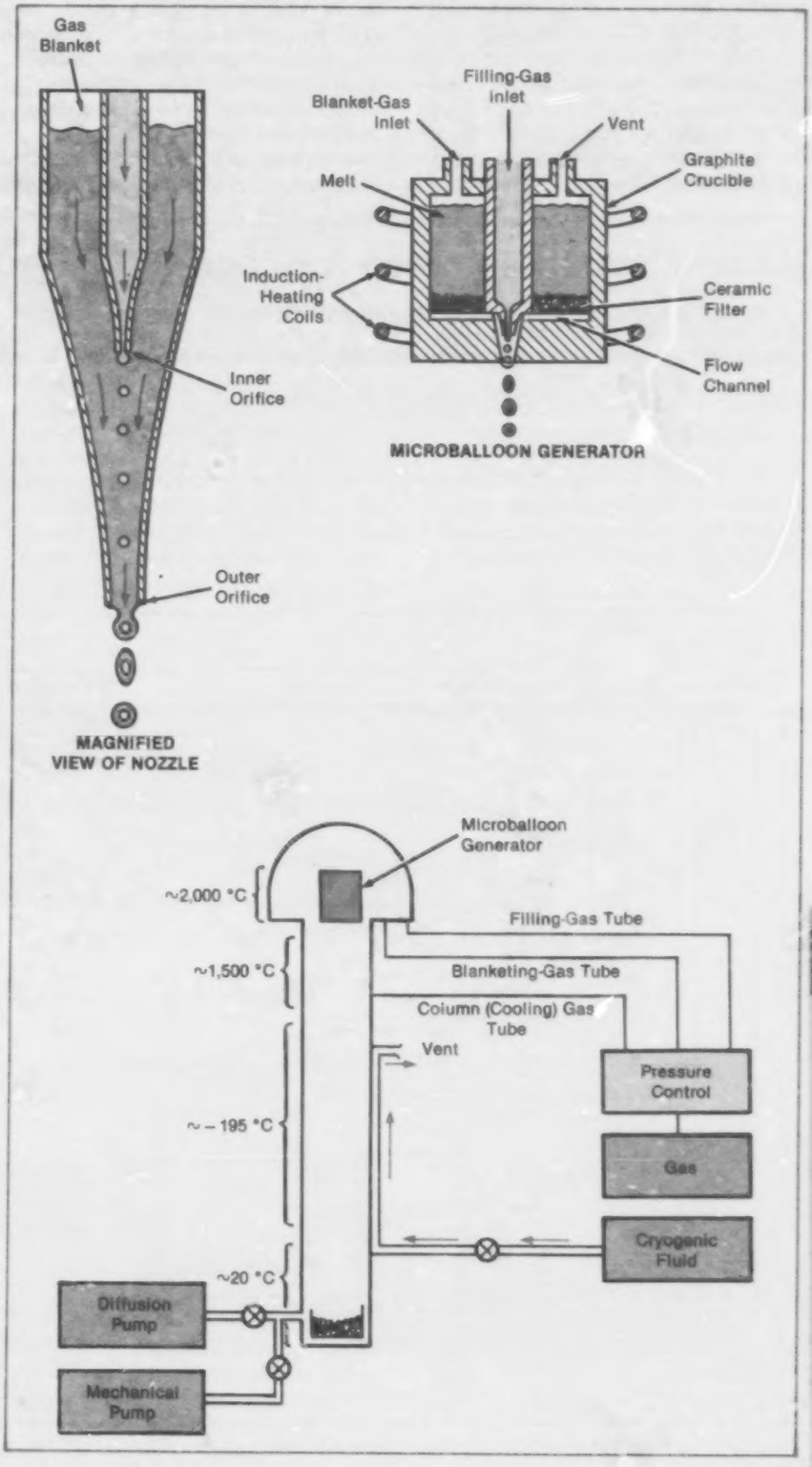
NASA's Jet Propulsion Laboratory, Pasadena, California

An apparatus produces tiny spherical shells, or microballoons, from refractory metals, ceramics, and glasses. The microballoons are generated at rates of 400 per second or higher with uniform shape and size. The size is selected from a wide range of diameters, ranging from 800 μm to less than 150 μm.

As in previous processes, microballoons are formed in two stages: Liquid-shell generation and free-fall solidification. Gas is ejected from an inner orifice into molten shell material in an outer orifice, thus forming a bubble that hardens as it falls through a vertical chamber. The new process, however, has several improvements over previous processes:

- The inner orifice is now recessed (see figure) instead of being coplanar with the outer orifice; as a result, the outer orifice can be fabricated with a smaller diameter than if it had to contain the inner orifice; therefore, smaller balloons can be generated;
- The Bernoulli acceleration in the flowing molten material in the nozzle as it converges toward the orifice tends to center the gas bubble in the emerging microballoon; thus, precise concentricity of the inner and outer orifices is no longer necessary;
- The recess distance of the inner orifice reduces the possibility of blockage of the outer orifice by impurity particles entrained in the melt; a ceramic filter further reduces the chances of undissolved particles from reaching the outer orifice; and
- The nozzle and crucible are made of the same material to eliminate differences in thermal expansion; this reduces the incidence of gross misalignment, overstress, cracking, and leakage.

In many cases, the crucible and nozzles could be made of machinable graphite, which is compatible with a variety of molten substances including refractory ones. With conventional machining, the inner orifice diameter can be made as small as 50 μm, enabling the formation of microballoons less



Key Components of equipment for the new microballoon fabrication process are the nozzle, crucible assembly, and drop tube. The recessed, conical inner orifice aids in producing uniform, symmetrical microballoons. The all-graphite crucible assembly is resistant to misalinement and cracks. The drop tube ensures timely solidification of the microballoons.

than 150 μm in diameter. Even orifices as small as 1 μm can be made with such techniques as chemical vapor deposition, laser machining, and slip casting. Materials other than graphite can be selected for special applications.

The inner nozzle is an integral part of the filling-gas tube, which supplies gas for bubbles at a constant flow rate. The flow of the melt is regulated by the pressure of a gas blanket above the melt in the crucible. The crucible and nozzle assembly is enclosed in a bell jar above a vertical drop tube.

The temperature decreases from the top to the bottom of the drop tube. This allows the normal oscillations of the liquid shell — which promote centering of the gas core in the shell — to dampen before the shell solidifies. Otherwise, the shell could contain frozen oscillation ripples on its surface. At the same time, the temperature profile is chosen to prevent solidification from occurring too late in the fall, when aerodynamic forces would have distorted and decentered the microballoon.

The drop tube is 45 ft (13.7 m) long. For a melt at a typical temperature of 2,000 °C, the gas in the upper part of the chamber might be kept at or near 1,500 °C. The microballoons then enter a cryogenic zone kept at about −195 °C for rapid quenching. Finally, the microballoons collect in a room-temperature zone at the bottom of the chamber.

The product has many applications. The microballoons can be used, for example, in fluidized-bed heat exchangers; as containers for hazardous materials; catalysts in chemical and pharmaceutical processes; solid fuel for rockets; fuel containers for fusion power experiments; shock-wave dampers; and starting materials for high-strength, low-density sintered alloys and ceramics.

This work was done by Mark C. Lee, Christopher Schilling, George O. Ladner, Jr., and Taylor Wang of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 32 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 27]. Refer to NPO-16489.

Laser Vacuum Furnace for Zone Refining

A laser beam is scanned to produce a moving melt zone.

Marshall Space Flight Center, Alabama

An experimental laser vacuum furnace scans a crystalline wafer with a high-power CO_2-laser beam to generate a precise melt zone with precise control of the temperature gradients around the zone. Intended for the zone refining of silicon or other semiconductors in low gravity (where convection would be suppressed), the apparatus can also be used in normal gravity.

The wafer is mounted in a vacuum system near a set of salt windows that

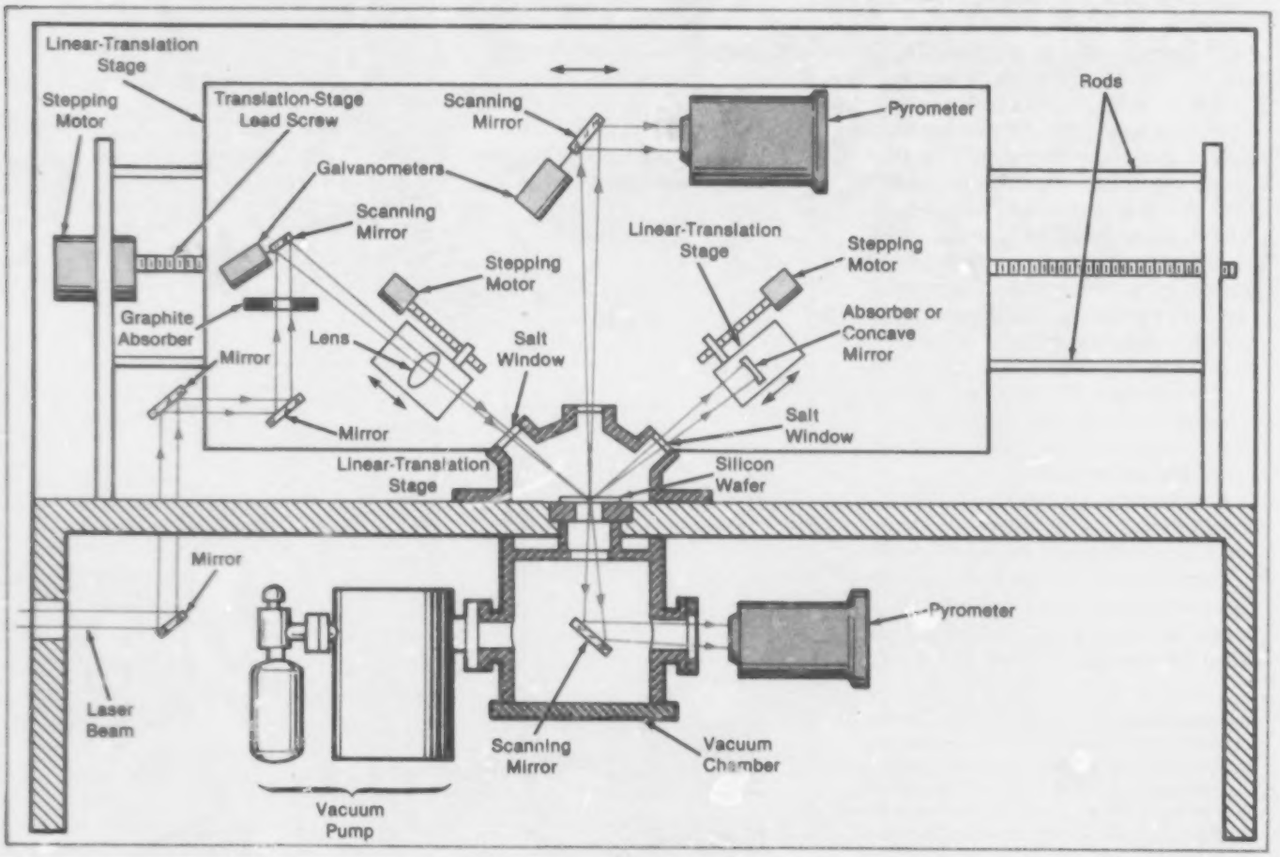


Figure 1. The **Laser Vacuum Furnace** includes a vacuum system with windows to admit the laser beam and a system of scanning optics to move the beam over the surface of the water to be heat treated.

permit the passage of infrared and visible light (see Figure 1). A system of mirrors mounted on a large translation stage directs the laser beam toward the wafer. A graphite absorber has a hole in the middle to allow the beam to pass but stops the beam if it becomes laterally misaligned. A lens mounted on a small linear translation stage focuses the beam to a spot on the wafer. By the motion of its transaction stage, the lens is focused or defocused slightly to obtain the desired spot size. The minimum spot diameter is about 0.5 mm.

The large translation stage moves slowly to the right or the left while the laser beam is scanned rapidly back and forth across the wafer (into and out of the page) by a scanning mirror on a galvanometer. When driven by a triangular wave at any convenient frequency up to about 60 Hz, the laser spot moves in the zigzag pattern shown in Figure 2. The horizontal spacing between lines is exaggerated here. To an observer, the illuminated region looks like a perpendicular line that coincides with the melt zone as it moves along the wafer.

A second small translation stage on the large stage holds an absorber to trap the portion of the laser beam reflected from the sample. Alternatively, the stage could hold a concave mirror to reflect this energy back onto the wafer to increase the heating efficiency. In this case, the stage is driven in synchronism with the beam-scanning galvanometer but at such a phase that the incident and back-reflected spots move in opposite directions across the wafer within the melt zone.

The temperature in the melt zone is monitored by either or both of two pyrometers that view the wafer perpendicularly to its surface. A scanning mirror moves in synchronism with the large translation stage to keep the melt zone within the view of the operating pyrometer.

A control computer (not shown) coordinates the operation of all the equipment. It monitors the laser output power, controls the laser power supply, generates the driving waveforms for the scanning galvanometers, and commands the stepping motors. The computer can be programmed to provide scanning speeds, scanning patterns, and laser powers over a wide range, thereby providing a range of melt-zone movements and temperature distributions.

This work was done by Donald B. Griner, Frederick W. Zurburg, and Wayne M. Penn of Penn-Penn Research Corp. for **Marshall Space Flight Center**. *For further information, Circle 145 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

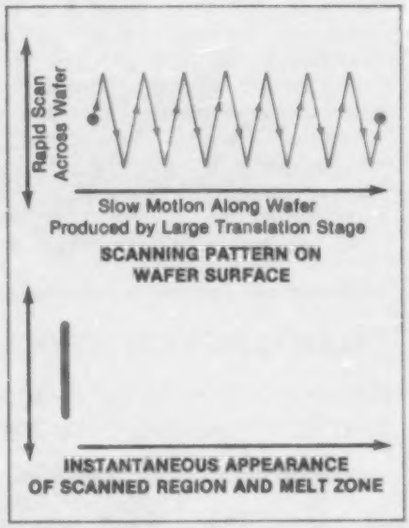

Rapid Scan Across Wafer
Slow Motion Along Wafer
Produced by Large Translation Stage
SCANNING PATTERN ON WAFER SURFACE
INSTANTANEOUS APPEARANCE OF SCANNED REGION AND MELT ZONE

Figure 2. The **Laser Beam Scans** rapidly across the wafer while the wafer moves to the right or left. Since the crosswise scan is much faster than the lengthwise scan, to a human observer the scanned zone looks like a vertical line coincident with the melt zone at any given moment.

Penn-Penn Research Corporation
2652 South Main Street
P.O. Box 3357
Kennesaw, GA 30144

Refer to MFS-26043, volume and number of this NASA Tech Briefs issue, and the page number.
MFS-26043

Storing Chemicals in Packed Spheres

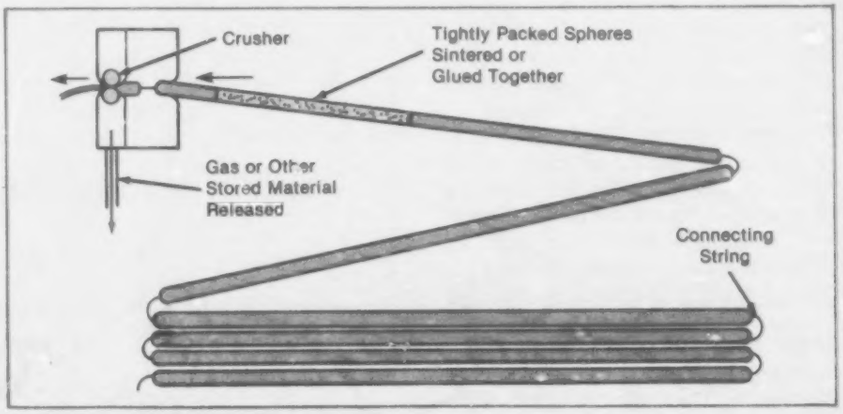
Reactants would be released by crushing or puncturing.

NASA's Jet Propulsion Laboratory, Pasadena, California

According to a concept for material storage, chemical reagents or other substances would be encapsulated separately in small, densely packed spheres. The spheres could be made of metal or other suitable material. They could be loose, forming a pourable mass, sintered, or glued together in a rigid structure (see figure).

The filling material could be a gas — for example, hydrogen to be burned as a fuel. There are two advantages to storing hydrogen in this way: Small quantities can be dispensed as needed, and a leak is likely to involve only the small volume of one or a few spheres, thereby presenting a smaller-than-usual risk of explosion.

Some of the spheres in a mass could be



Agglomerated Gas-Filled Spheres are hexagonally close packed and sintered or glued together into rods that are strung together at their ends. The rods are fed into a crushing machine to release the material in the spheres as it is needed.

filled with an epoxy resin or other monomer, while others could be filled with the corresponding hardener or catalyst. The spheres would be manufactured in the required ratio and mixed together in forming the mass. The catalyst and resin would be released for mixing by puncturing or crushing the required number of spheres at the mixing site.

Another variation might be the permanent storage of reusable materials in capsules — for example, magnetic material for use in magnetic brakes. The flowing magnetic material tends to agglomerate, thereby preventing the necessary even distribution over the magnetic-braking area. In such an application, agglomeration might be controlled by storing the magnetic material in small, loose aluminum spheres.

This work was done by Taylor G. Wang and Daniel D. Elleman of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 49 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 27]. Refer to NPO-16316.

Multifunction Vacuum Chamber for IC Metallization

One system performs several operations without transferring wafers between vacuum chambers.

Marshall Space Flight Center, Alabama

A vacuum system chamber for processing multilayer metallization on integrated circuits (IC's) performs four operations ordinarily done in separated equipment. The chamber etches holes, removes photoresist, cleans by sputter etching, and deposits the final layer of metal.

The combined-function chamber costs less than the separate equipment performing the same functions. The chamber avoids exposing the integrated circuits to room air and, consequently, to oxidation and dust, between steps. It also eliminates the time spent in transferring the circuits from one apparatus to the next.

Unlike the conventional process, the multifunction process does not use liquid acids and reducing agents for hole etching and photoresist removal. The cost of disposing of these hazardous materials is therefore avoided.

The chamber (see Figure 1) contains turntables that continuously turn silicon integrated circuit wafers to ensure uniform processing of several wafers at a time. It also contains radio-frequency and magnetron sputtering guns. External tanks furnish gases to the chamber.

Wafers are introduced into the chamber after transistors or other circuit elements have been formed in them and after layers of oxide, metal, more oxide, and photoresist have been built up. Holes yet to be formed are delineated by the photoresist pattern. In the first vacuum processing step, a mixture of helium, oxygen, and a chlorofluorocarbon gas is admitted to the chamber, forming a plasma under the radio-frequency sputtering gun. A permanent magnet directs the plasma to the wafer surface, where it etches away the oxide

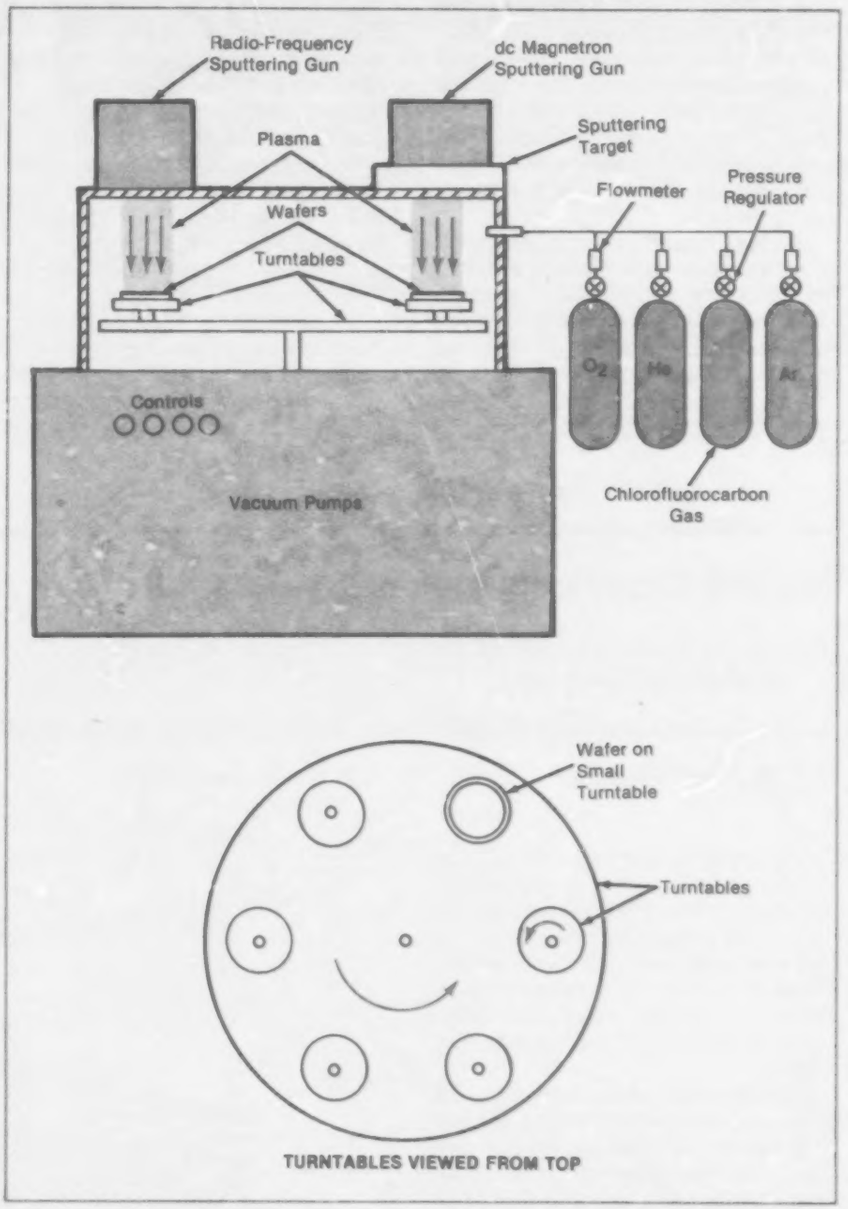


Figure 1. **External Tanks Supply Gases** to the vacuum chamber for forming plasmas. Permanent magnets direct the plasmas to the wafers as they pass under the sputtering guns. The wafers are continuously rotated about their own centers and about the center of the upper turntable for uniform coverage.

in the holes, exposing the metal layer at the bottoms of the holes (see Figure 2). When etching is done, the gas mixture is pumped out.

In the second step, oxygen is admitted and forms an oxygen plasma under the radio-frequency sputtering gun. This plasma etches away the photoresist layer. It also forms aluminum oxide at the bottoms of the newly etched holes. The oxide layer prevents the formation of good contacts and must be removed.

After the oxygen has been pumped out, argon is admitted. The argon plasma under the radio-frequency sputtering gun cleans the entire wafer surface, removing the aluminum oxide from the bottoms of the holes. The argon is then pumped out.

In the fourth step, the magnetron sputtering gun deposits a layer of metal from a target onto the wafers. This layer is the upper conductor and joins the lower conductor through the holes. The wafers can now be removed from the chamber for further processing.

This work was done by Donald E. Routh and Gian Sharma of **Marshall Space Flight Center.** *For further information, Circle 92 on the TSP Request Card.*

This invention has been patented by NASA (U.S. Patent No. 4,437,961). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 27]. Refer to MFS-25670.

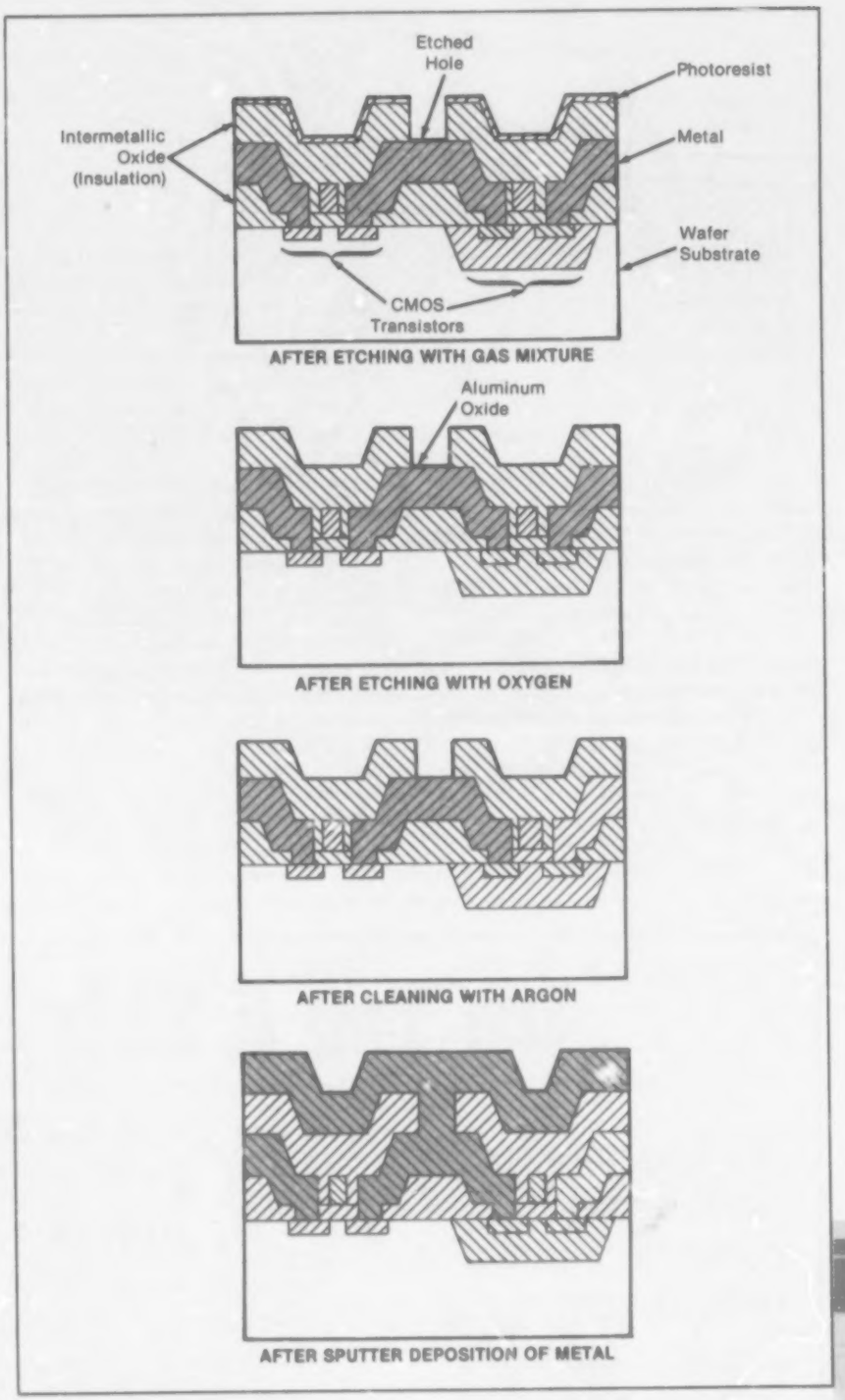


Figure 2. The **Layer Structure** of a silicon wafer changes at each processing step. The wafer structure shown here contains complementary metal-oxide/semiconductor (CMOS) transistors.

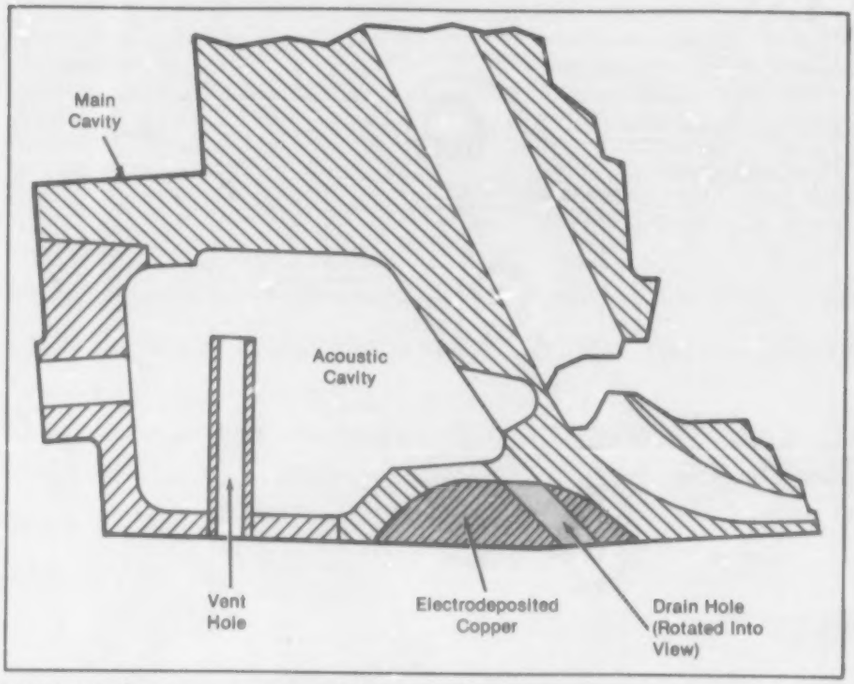
Covering Cavities by Electrodeposition

A reworking technique allows complex surfaces to be reshaped.

Marshall Space Flight Center, Alabama

The contours of large machined parts can be reworked quickly and inexpensively by electrodeposition and machining, with little risk of damage. The reworking method employs simple, reliable, well-known procedures.

The method was used to modify for testing the main combustion chamber of the Space Shuttle main engine. Thirty



Electrodeposited Copper Closes Off an acoustic cavity near the main cavity. A hole through the wall vents these two cavities to each other.

acoustic cavities adjoining the combustion chamber had to be sealed off to eliminate their stabilizing effect during a hot-fire test.

The cavities were filled with wax. A groove was machined around the inside circumference of the main combustion chamber wall to a depth of 0.3 in. (7.62 mm). The groove passed through the acoustic-chamber openings. Copper was then electrodeposited in the groove until the surface of the deposit protruded slightly out of the groove. The copper was then machined so that it was flush with the chamber wall (see figure).

For the combustion-chamber test, it was necessary to vent the acoustic cavities. Another hole was drilled through the electrodeposited copper into the bottom of one cavity so that liquid accumulated in the cavities could drain.

This work was done by Melissa Schmeets and Joe Duesberg of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-29084

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Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Levitation With a Single Acoustic Driver

Using one driver instead of three makes levitation easier to control.

A pair of reports describes acoustic-levitation systems in which only one acoustic resonance mode is excited, and therefore only one driver is needed. The systems employ levitation chambers of rectangular and cylindrical geometries.

Until now, a typical acoustic levitator contained three acoustic drivers that produced three orthogonal acoustic waves or modes. However, there are many complicated interactions among the three drivers. It is necessary to monitor and continually adjust each driver to ensure that a sample remains levitated, does not rotate, and does not become distorted or broken up. The single mode levitators eliminate the interactions among drivers and are therefore simpler to operate. They thus make acoustic levitation more practical as a means of containerless processing of materials.

The reports first describe the single mode concept and indicate which modes can be used to levitate a sample without rotation. Each of these single modes has one or more unique positions inside the chamber at which the sample will stably levitate. Thus, the location of the sample inside the levitation chamber can be controlled by choosing the appropriate single mode.

The reports then go on to describe systems in which controlled rotation of the sample can be introduced. For both geometries, one primary driver is used to excite a single mode for levitation as described above. Auxiliary drivers are used to excite other modes to rotate the sample. The axis of rotation is chosen by selection of appropriate chamber dimensions and the auxiliary modes. These new driver configurations differ from a rectangular three-axis levitator with rotation in that the levitation and rotation controls are separated from each other.

This work was done by Martin B. Barmatz, Mark S. Gaspar, and James L. Allen of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the reports, "Single Transducer Rectangular Levitator" and "Single Transducer Cylindrical Levitator," Circle 131 on the TSP Request Card.*

This is the invention of a NASA employee, and a patent application has been filed. Inquiries concerning license for its commercial development may be addressed to the inventor, Mr. Edward Ansell (CIT Waiver), Director of Patents and Licensing, California Institute of Technology, Pasadena CA 91125. Refer to NPO-16246/NPO-16376.

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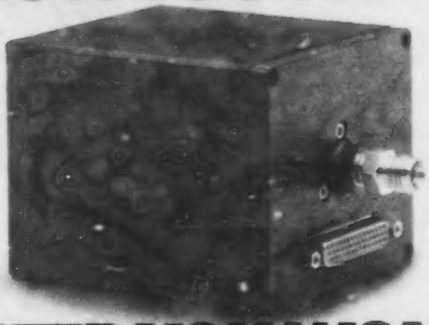

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Mathematics and Information Sciences

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90 **Multiple Grids in Finite-Difference Flow Analysis**
92 **"Noiseless" Data-Compression Algorithm**

Computer Programs

61 **NASA Test File**

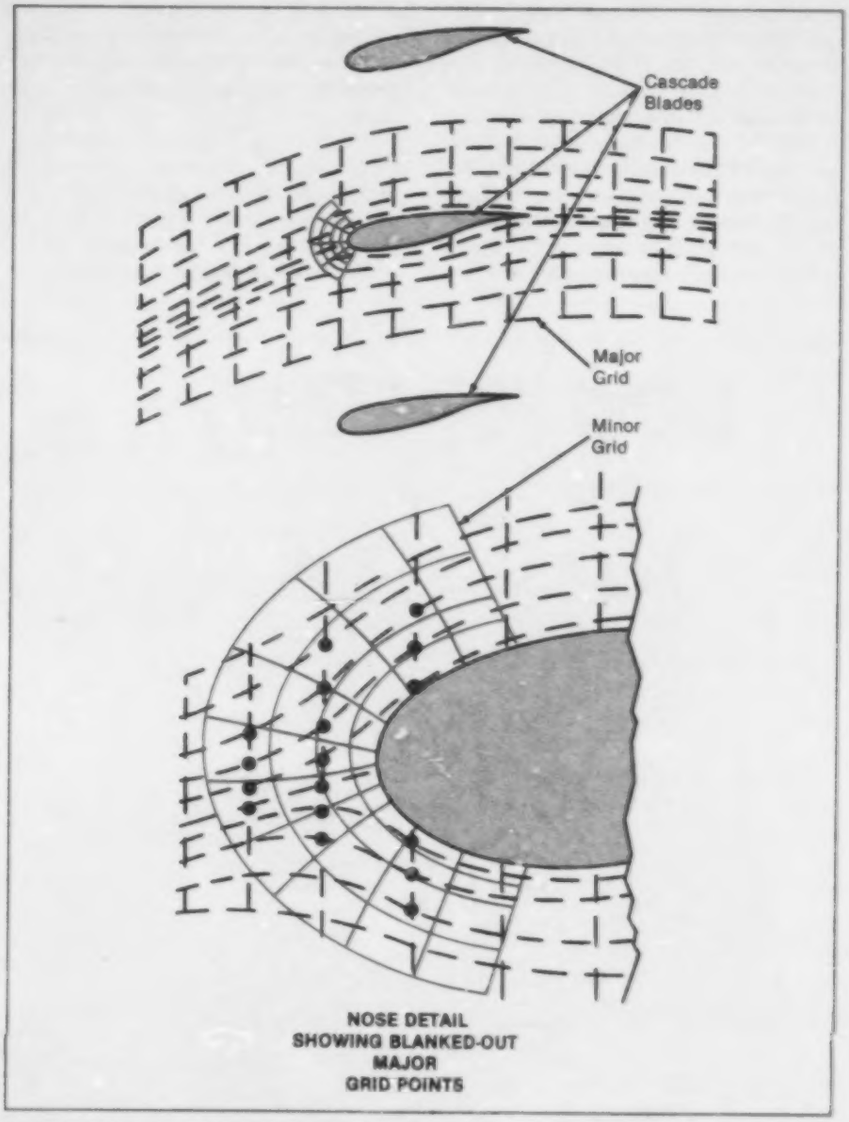
Multiple Grids in Finite-Difference Flow Analysis

Multiple solutions are superimposed to resolve flows about complex configurations.

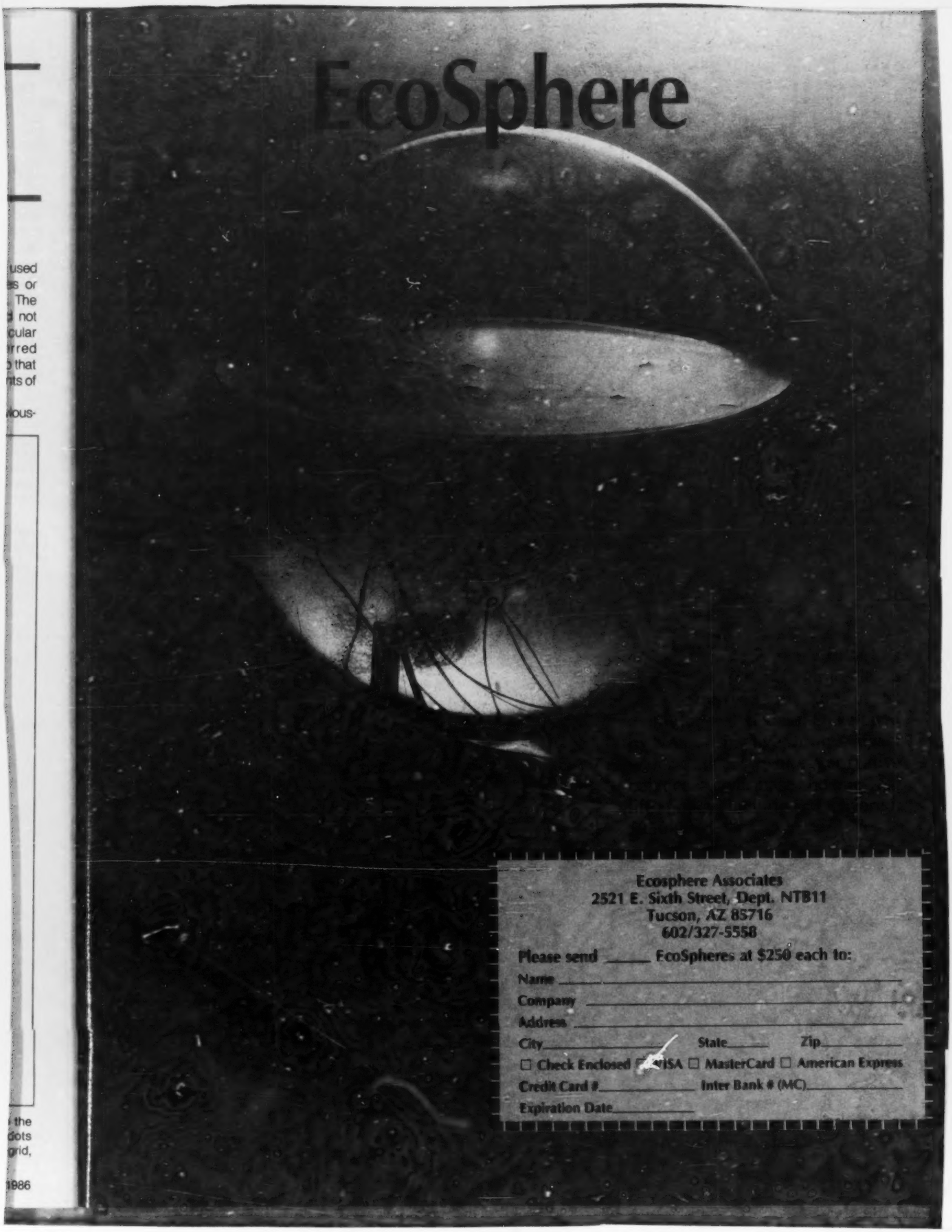
Ames Research Center, Moffett Field, California

The use of multiple, overset grids in computational fluid dynamics extends the application of finite-difference methods to more complex configurations. Rather than trying to generate a single mesh about all components of a configuration, multiple, individual meshes are used, then overset on a major grid. The major grid may be used to resolve the flow field or may be wrapped around the main component. One or more minor meshes may be used to resolve flows around appendages or near singularities in the main grid. The boundaries of the minor grids need not conform to the major grid in any particular way. Boundary data are transferred among the meshes each time step so that all meshes are aware of all components of the flow field.

Overset grids have been used previous-



Overset Grids are used here for cascade blade analysis. A minor grid that conforms to the blade nose is used to resolve the flow field in that region. In the detail drawing, the black dots indicate the points in the major grid that are blanked out during computations on that grid, which are then updated by interpolation from the minor grid.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ly for other types of flow problems, such as transonic flow about airfoils, using the potential equation and resolution of gradient regions in two-dimensional shallow water equations. This study applies overset grids to an existing class of implicit finite-difference algorithms for solving the stream-function equation and the Euler equations. These applications show that the technique can be handled within a general framework, that grid generation about complex configurations can be simplified, and that only minor modifications to existing flow solvers are necessary when combined with this grid approach.

The cases studied were all two-dimensional aerodynamic applications. In the case shown in the figure, a rectangular major grid fits well along a cascade blade element everywhere except at the blunt nose region. A minor grid is wrapped about the nose to resolve the flow suction peak. Flow variables at the boundaries of the minor grid are interpolated from the major grid. The dot-marked points in the major grid near the nose are blanked; that is, omitted from the computations. Instead, the flow values at the major grid points at the perimeter of the blanked area are found by interpolating results from the minor grid.

To use the overset grids, the finite-difference algorithms must be altered in three ways. First, the data base must be structured for a number of grids, rather than for just one. This can be done in various ways, depending on the architecture of the computer used. Second, the algorithm must skip blanked points. In approximate factorization algorithms and other time-like algorithms, blanked points are excluded by multiplying by a flag array that contains a 0 or 1 for each grid point, indicating exclusion or inclusion, respectively. Third, the boundary conditions must be recoded in a modular fashion to allow for the possibility that a minor grid may require a boundary-condition treatment different from that of the major grid.

Grid boundary data have been interpolated from one grid to the other with second-order Taylor-series approximations. This simple technique does not maintain conservation of mass, energy, or momentum; for example, while the flow equations may be differenced in divergence form, the divergence property is not numerically preserved if some of the values are obtained by interpolation. This could be a problem if a jump discontinuity, such as a shock wave, were to cross the interpolation boundary. In that case, the interpolated values could be adjusted to satisfy a numerical line integral of flux.

This work was done by F. Carroll Dougherty of **Ames Research Center**, *Joseph L. Steger of Stanford University and John A. Benek of Calspan Corp. For further information, Circle 138 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center, [see page 27]. Refer to ARC-11491.

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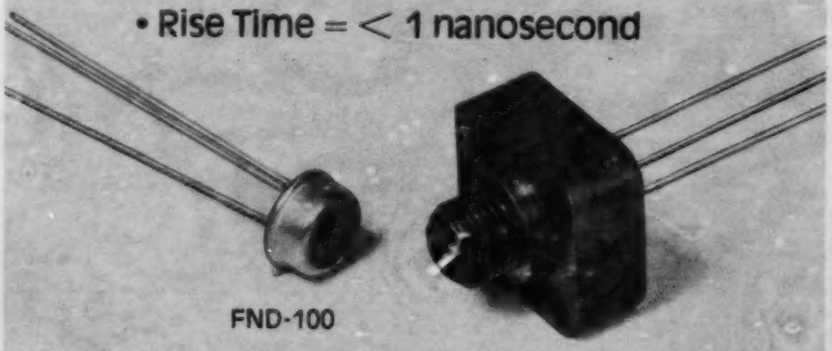

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"Noiseless" Data-Compression Algorithm

Gamma-ray spectrometer data are compressed to enable more frequent sampling.

NASA's Jet Propulsion Laboratory, Pasadena, California

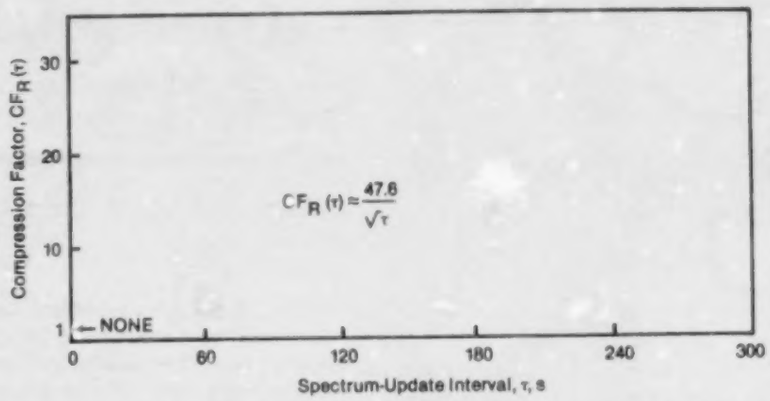
A proposed data-compression algorithm will efficiently represent gamma-ray spectrometer spectra at any spectrum collection interval from 5 seconds to 5

minutes. The data representation is "noiseless" (data can be exactly reconstructed). Depending on the spectrum interval, compression factors of from 2.5:1 to 2?:1 compared to a standard spectrum representation were demonstrated (see figure). The techniques would be useful in designing data-compression algorithms for other spectral instruments, which have varying data-rate requirements.

For the gamma-ray case, the raw spectra are 8,192-bin histograms in which the expected number of counts per bin decreases by a factor of 1,000 in going from the low to the high energy end of the distribution. Additionally, varying the collection interval could change the expected number of counts in all the bins by as much as a factor of 60.

The proposed approach applies adaptive variable-length coding techniques to large blocks of energy bins. The algorithms automatically adapt to changes in block statistics resulting from the position in the overall spectrum or changes in the collection interval. Only the general shape of the spectrum is needed as a priori knowledge. Test results demonstrated performance close to a theoretic minimum for a coder that incorporated separate coders for each energy bin (optimally designed from known Poisson distributions).

Under one set of assumed conditions, the transmission of a spectrum every 30 seconds would require 2,500 bits/s, using the standard representation, whereas the compression algorithm would enable the transmission of a spectrum every 10 seconds, using only 500 bits/s. The compression factor representing the shortening of the sampling interval is plotted in the figure as a function of the data rate.



The **Data-Compression Factor** achievable with one version of the proposed data-compression algorithm decreases asymptotically with the spectrum-update interval.

An experimental encoder using this scheme was built with an 8086 microprocessor, 1 Kbyte of memory for instructions, and 1 Kbyte of memory for internal buffers. The associated decoder was only about half as complex. The throughput capability of this system was about 20 Kbits/s.

This work was done by Robert F. Rice and Jun-Ji Lee of Caltech for **NASA's Jet Propulsion Laboratory.** *Further information may be found in NASA CR-176201 [N85-35219/NSP], "Noiseless Coding for the Gamma-Ray Spectrometer."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
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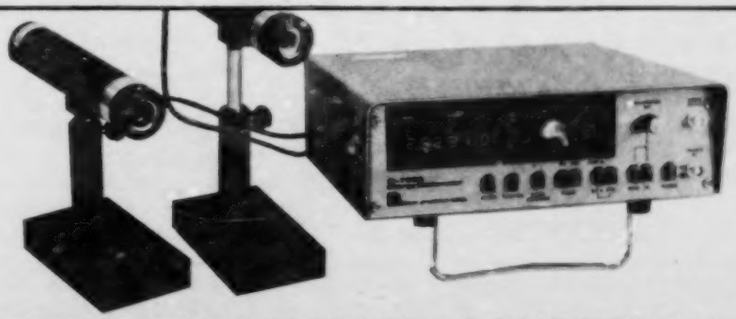

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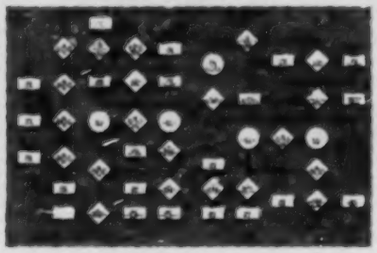

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Life Sciences

Hardware, Techniques, and Processes

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Photoelectronic Monitor of Motion Sickness

An instrument measures the drop in skin infrared reflectance accompanying nausea.

Lyndon B. Johnson Space Center, Houston, Texas

The nausea that accompanies human motion sickness is monitored by an instrument that records the reflectance of the skin at a wavelength of 940 nm. Pale skin, a cardinal symptom of motion sickness, is probably caused by a decrease in the volume of blood in the microcirculation system of the skin, although the mechanisms that trigger it are not yet understood.

The instrument includes a gallium arsenide light-emitting diode (LED) and a silicon phototransistor with an infrared filter, all cast in a single plastic housing. The housing is attached to the subject's face with transparent double-sided adhesive tape. The LED directs pulses of infrared light to the skin, which reflects them to the phototransistor. The phototransistor produces a signal that is processed by external circuits to yield a plot of infrared reflectance with time. The external circuits are temperature-compensated and respond only to the pulsed component of the detector output, rejecting those components caused by stray light. The circuits also extract the blood-volume pulse amplitude and the heart rate.

The amplitude of the LED pulses can be adjusted so that the light reflected to the detector can be standardized; the instrument therefore works equally well on dark-skinned and light-skinned people. The LED power is low enough to have a negligible skin-heating effect.

Tests of the instrument were made on subjects who were asked to make head movements while seated in a rotating chair or while wearing left/right vision reversal goggles. The onset and remission of pallor and extent of pallor, as measured by the instrument, correlate well with reports of nausea by the subjects and with changes in skin temperature (see figure) measured elsewhere on the face.

This work was done by Charles M. Oman and Walter J. C. Cook of the Massachusetts Institute of Technology for **Johnson Space Center.** *No further documentation is available.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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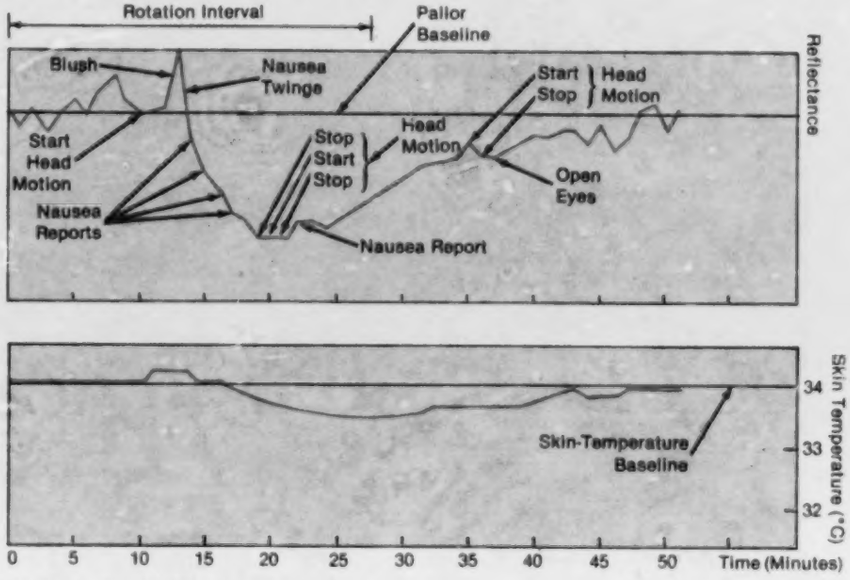
Refer to MSC-20794, volume and number of this NASA Tech Briefs issue, and the page number.



This Recording of Pallor for a test subject also shows periods of head movement and reports of nausea. The peak of the curve indicates a transient blush that precedes nausea in some subjects. The label "rotation" indicates the period during which the seated subject was spun at 54 degrees per second.

Books and Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Collection of Human Wastes on Long Missions

A report evaluates and compares three alternative approaches to hygienic containment of human wastes.

A report presents a study of methods for the collection of human wastes. The findings of the study, which was done for the Space Shuttle and space stations, are potentially useful in airplanes, buses, boats, trains, and campers and in temporary toilets for construction sites and outdoor gatherings.

The primary requirements for acceptable waste collection on long missions are effective and hygienic separation of the waste from crewmembers and storage in a safe, odorless form in a place separated from the crew compartment. The waste-collection equipment should retain waste and paper for at least 210 person-days. It should be quickly and easily replaceable in flight and disposable on the ground.

The study identified three practical means of waste collection: (1) filter-bag collection with compaction by fan suction, (2) canister collection with compaction by force applied to compaction cups or disks, and (3) sleeve collection with compaction by rollers and winding on a reel. The report notes that canister collection and compaction are more acceptable to crews than bag collection and compaction and are more reliable than sleeve compaction. Canister collection therefore is preferable.

The study was conducted on the premise that waste-collection methods used successfully on the Space Shuttle should be retained. These methods have employed the following:

- Sanitation and odor control by containment, seals, inward airflow, and filters; and
- Mechanical waste separation from the crewmember by crewmember positioning, seat, air jets, slide valve, transport tube, and airflow.

For long missions on a space station, nonventing treament by microwave drying, thermoelectric refrigeration, and biodegradation were found to be acceptable.

This work was done by David C. Jennings, Tod A. Lewis, and Harlan F. Brose of United Technologies Corp. for **Johnson Space Center.** *Further information may be found in NASA CR-171836 [N85-17552/NSP], "Waste Collection Sub-system Study"[$13]. A copy may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center [see page 27]. Refer to MSC-20968.

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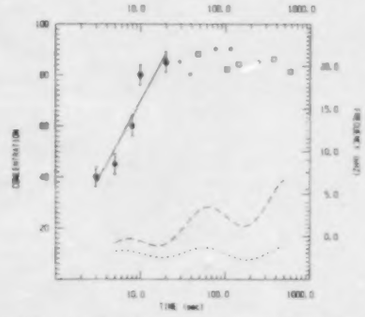

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Mission Accomplished

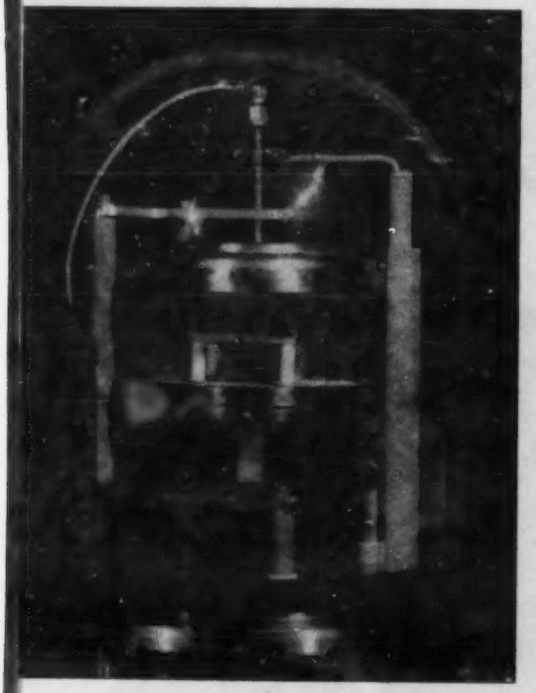
Through the technology transfer process, many of the systems, methods and products pioneered by NASA are re-applied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.

Dr. Theodore Wydeven wearing a pair of the "Space Tech" sunglasses.

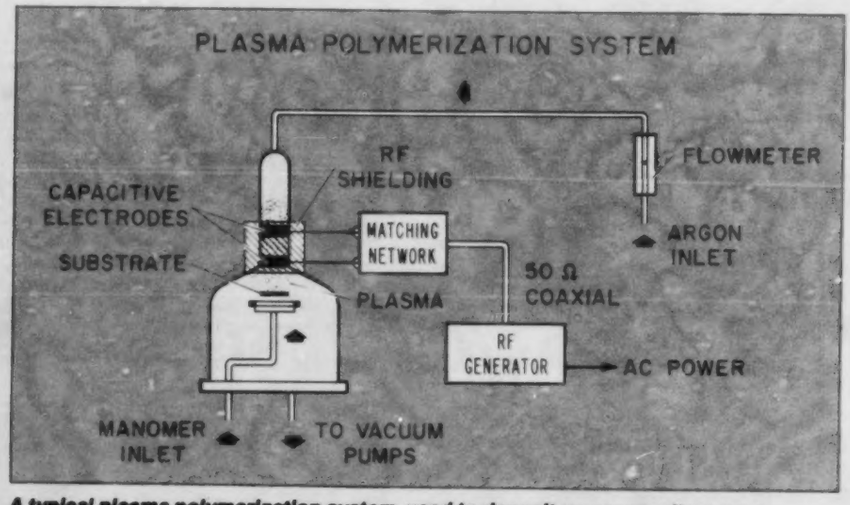
The NASA Ames research scientist peering over his new Foster Grant sunglasses, Dr. Ted Wydeven, developed a chemical process that significantly improves sunglass lens technology. A greater degree of lens hardness and, consequently, greater scratch resistance is achieved by depositing a thin plastic coating on a dissimilar plastic sheet. Under normal wear conditions, the new scratch-resistant lenses last ten times longer than the most widely used plastic optical lenses. The moderately priced sunglasses are sold under the trade name "Space Tech."

While improving a spacecraft water purification system, the physical chemist at the Ames Research Center discovered the key elements for this new technology. To modify the thin, semipermeable membranes used in the purification process, a porous filter was coated with a thin plastic semipermeable film using an electric discharge of an organic vapor. Later, an abrasion-resistant coating and process for polycarbonate visors was developed for NASA space helmet visors. Increased surface hardness, or scratch resistance, results from a process in which organosilane compounds are plasma polymerized and then treated for a short time with an oxygen glow discharge. More than five million pairs of sunglasses have been coated using this process since 1983.

Although ground and polished tempered glass has traditionally been the preferred lens in the eyeglass industry, polarized and other plastic lenses have made important inroads in recent years due to their lower manufacturing costs, excellent optics, and better absorption of ultraviolet radiation. In addition, they are lightweight, resistant to shattering, and easier to shape. Susceptibil- ►



Plasma polymerization apparatus showing the deposition of an anti-reflection coating on a plastic lens. The vapor being used is Perfluorobutane - 2.



A typical plasma polymerization system used to deposit an organosilane on a plastic substrate.

ity to scratching and subsequent reduction of visibility have been the major limitations of plastic lenses. The coating process, made available through NASA licensing, substantially corrects these deficiencies.

Foster Grant Corporation, one of the world's largest manufacturers of non-prescription sunglasses, obtained a license from NASA to use the process in 1983. Since then, the resulting products have improved the company's sales by over $75 million. The new process, known as plasma or glow discharge polymerization, holds the NASA record for the most units made and sold under a NASA license and is second in highest royalties to NASA. □

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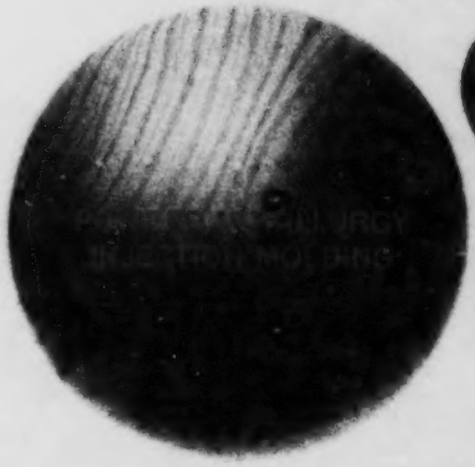

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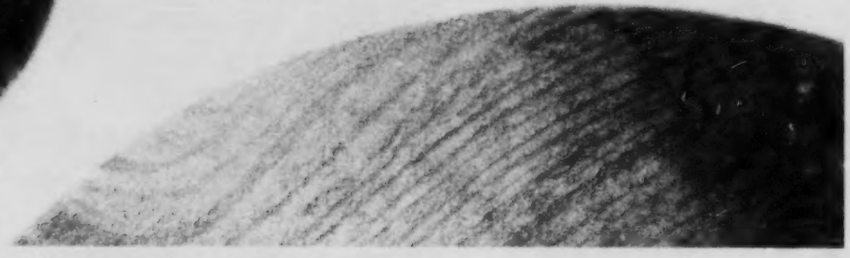

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Letters

The "Letters" column is designed to encourage a wide exchange of ideas among *NASA Tech Briefs* readers. To contribute a request for information or to respond to such a request, use the feedback cards in this issue, or write or call: Manager/Technology Transfer Division, P.O. Box 8757, Baltimore/Washington International Airport, MD 21240; (301) 859-5300. While we can print only a small number of letters, we will endeavor to select those that are of varied and wide interest.

IT'S OUR PLEASURE

Thank you and your staff for the Technical Support Packages on Foamed Materials and Water-Jet Coal Evacuation.

As usual you have been very prompt in your response to my request for information. The format of the documents I receive from you is informative and concise, which helps me considerably.

I know that your objective is to assist in the development of products and processes that will stimulate the creation of jobs and strengthening of the economic base of this country. I praise you for your efforts in this respect. If we are able to maintain our industrial position in the world, it will be through the development and dissemination of technology. Your efforts will play a great part in achieving that goal.

The information I have received has been a catalyst to me and my associates in our thinking, evaluations and problem solving efforts.

I am a firm believer in the Gestalt method of analysis, and your services have helped greatly in collecting information necessary to that process.

Again, I wish to say thanks to you and your staff. Your efforts and the efforts of others in the information dissemination process are, in my opinion, the mainstay of our nation's future.

Raymond D. James, Jr.
Architect
Ray James
Architect and Associates, Inc.
Ada, OK

We wish to extend our sincere thanks to NASA Tech Briefs for publishing our Multiple Output Sequencing Controller article (NTB, Mission Accomplished, Volume 10, Number 5). NASA Tech Briefs serves as a superb catalyst for enhancing the transter of information in the world of high tech. The mere fact that NASA Tech Briefs published a non-NASA contractor's design paper (an improvement over one of NASA's original circuits) shows that your periodical is unbiased, willing to show all facets of an idea, and truly devoted to aiding the engineering world in attaining its goals. All of these characteristics, combined with a flair for introducing the "human element," lead to a more interesting and readable source of information.

Once again—Thanks!!

Joseph D. King
John A. Carvalho
RCA Automated Systems Division
Burlington, MA

[Editor's note: Mission Accomplished highlights successful transfers of NASA technology to non-NASA use. Actual Tech Briefs are developed exclusively by NASA or its contractors.]

WE AGREE

It would be nice if you would publish more frequently, budget withstanding.

David J. Bassett
Software Engineer
Source Two Incorporated
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Subject Index

This document was prepared under the sponsorship of the National Aeronautics and Space Administration. NASA Tech Briefs is published bi-monthly and is free to engineers in U.S. industry and to other domestic technology transfer agents. It is both a current-awareness medium and a problem-solving tool. Potential products...industrial processes...basic and applied research...shop and lab techniques...computer software...new sources of technical data...concepts...can be found here. The short section on New Product Ideas highlights a few of the potential new products contained in this issue. The remainder of the volume is organized by technical category to help you quickly review new developments in your areas of interest. Finally, a subject index makes each issue a convenient reference file.

Further Information on Innovations—Although some new technology announcements are complete in themselves, most are backed up by Technical Support Packages (TSP's). TSP's are available without charge and may be ordered by simply completing a TSP Request Card, found at the back of this volume. Further information on some innovations is available for a nominal fee from other sources, as indicated. In addition, Technology Utilization Officers at NASA Field Centers will often be able to lend necessary guidance and assistance.

Patent Licenses—Patents have been issued to NASA on some of the inventions described, and patent applications have been submitted on others. Each announcement indicates patent status and availability of patent licenses if applicable.

Other Technology Utilization Services—To assist engineers, industrial researchers, business executives, Government officials, and other potential users in applying space technology to their problems, NASA sponsors Industrial Applications Centers. Their services are described on pages 26-27. In addition, an extensive library of computer programs is available through COSMIC, the Technology Utilization Program's outlet for NASA-developed software. See special section on computer programs on page 60.

Applications Program—NASA conducts applications engineering projects to help solve public-sector problems in such areas as safety, health, transportation, and environmental protection. Two applications teams, staffed by professionals from a variety of disciplines, assist in this effort by working with Federal agencies and health organizations to identify critical problems amenable to solution by the application of existing NASA technology.

Reader Feedback—We hope you find the information in *NASA Tech Briefs* useful. A reader-feedback card has been included because we want your comments and suggestions on how we can further help you apply NASA innovations and technology to your needs. Please use it; or if you need more space, write to the Manager, Technology Transfer Division, P.O. Box 8757, Baltimore/Washington International Airport, Maryland 21240.

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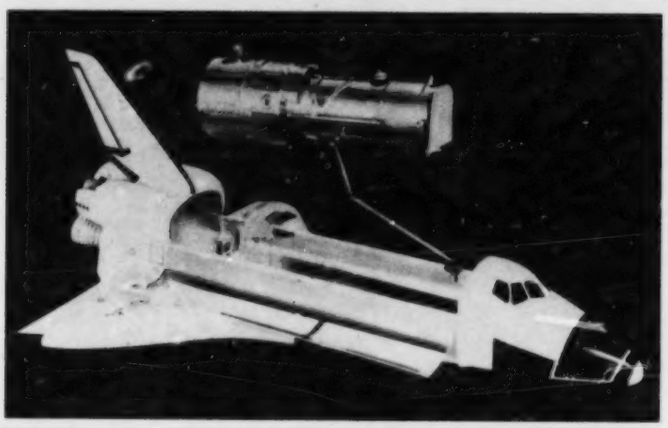
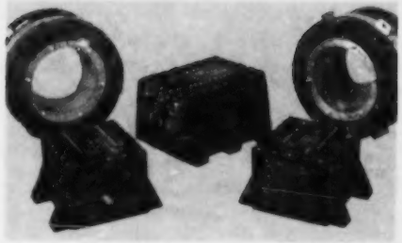


BEI's LED-equipped optical encoders help position the space shuttle arm and provide guide star position data on NASA's Hubble Space Telescope.



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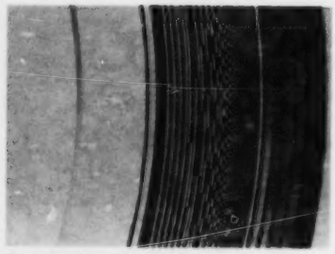

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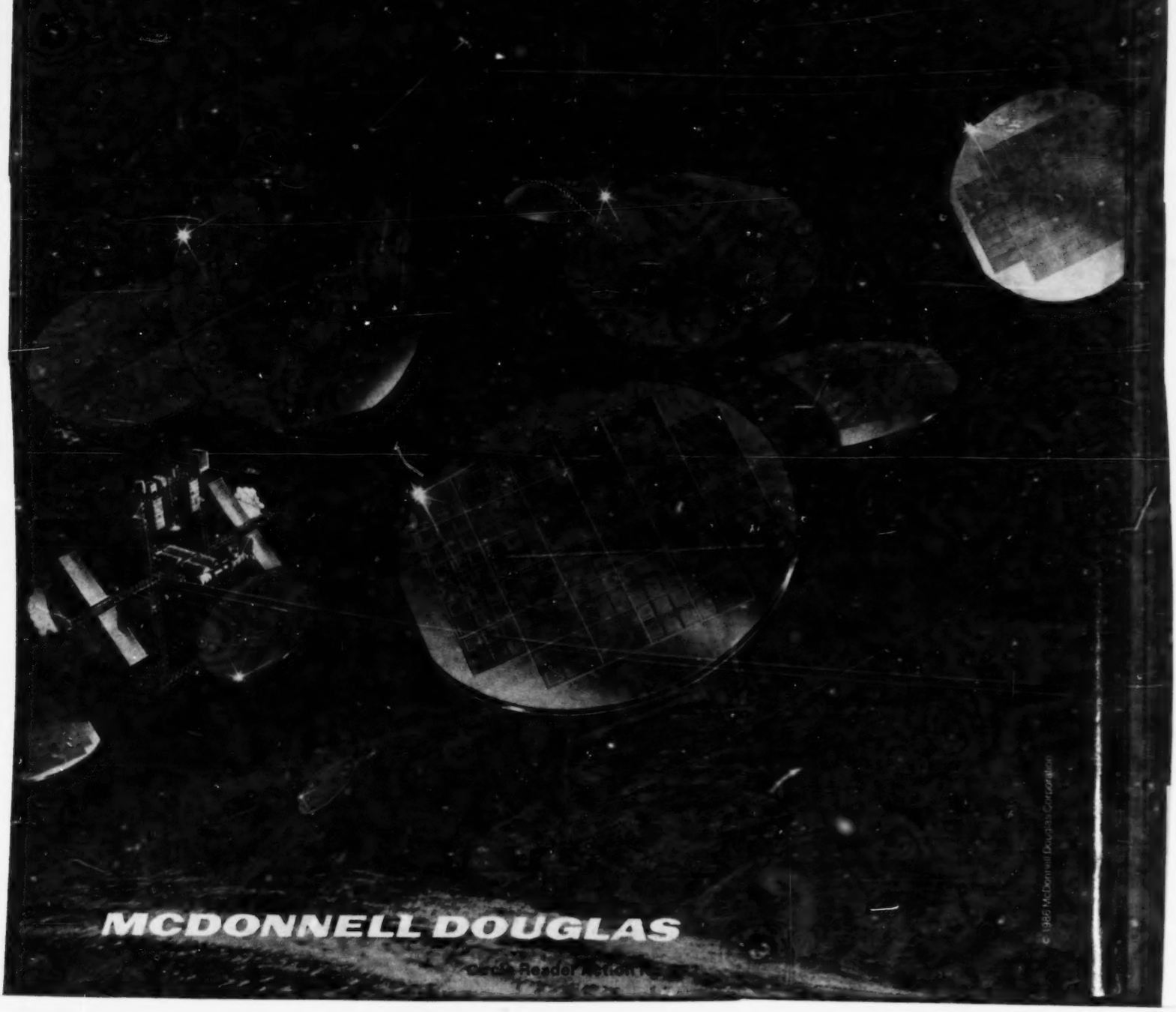

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National Aeronautics and Space Administration

November/December 1986

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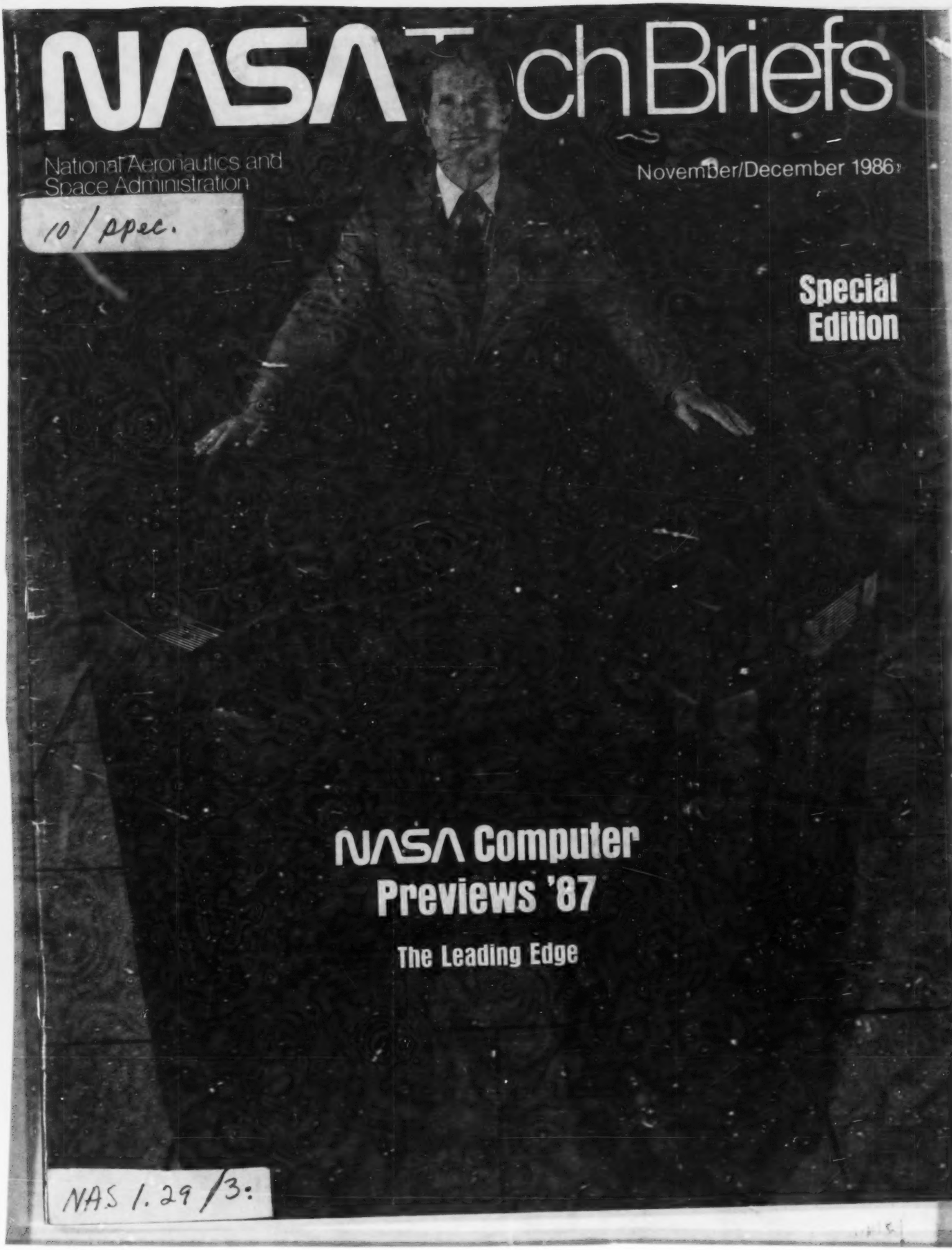

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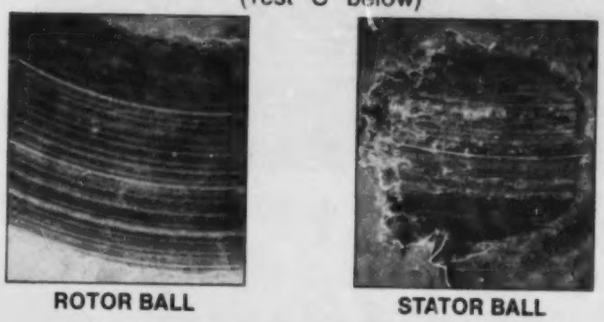

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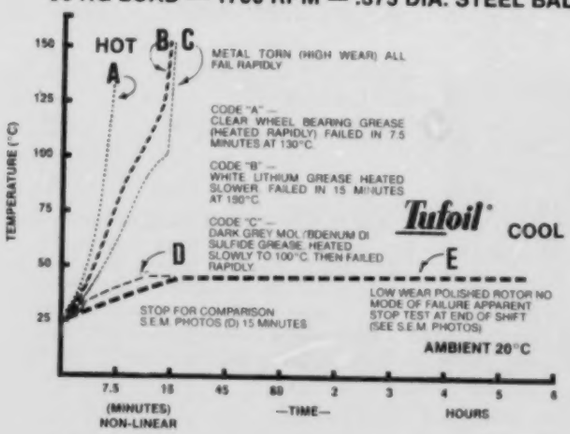

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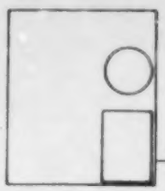
The newly developed TUFOIL LIGHTNING GREASE was tested for 15 minutes. The test was stopped at "D" so that S.E.M. photos of the balls could be made for comparison purposes. Both the rotor and stator marks appear polished and smooth. A great deal of super fine PTFE debris (teflon or fluon) can be seen at the bottom of the rotor photos. It is loosely bonded to the metal surface. Solvent rinsing will not easily remove it.

The wear areas on the stator were calculated, showing the spot on the control was 7.7 times larger than for TUFOIL grease (7.7 times the wear). Another test was set up with fresh balls ("E") and run for a full shift of 6 hours. The temperature stabilized at 50°C. The test was terminated with no mode of failure apparent. S.E.M. photos show highly polished surfaces with scar marks only slightly larger than those for "D" (the 15 minute sample).

We then life tested for 7 days (7 hours per day) . . . no failure and less wear than the moly disulfide produced in 15 minutes.



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NOVEMBER/DECEMBER 1986
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On the cover: Dr. William F. Ballhaus, Jr., Director of the NASA Ames Research Center, is standing with the Cray-2 supercomputer, the initial high-speed processor for the Ames Numerical Aerodynamic Simulation (NAS) system. The NAS description begins on page 20.

At Kennedy Space Center, expert systems will help plan launches around severe weather. More information on NASA's artificial intelligence applications can be found on page 24.

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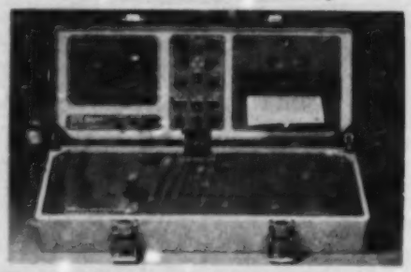

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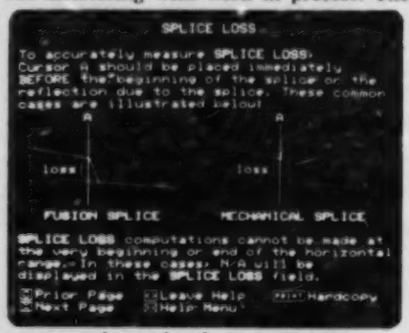

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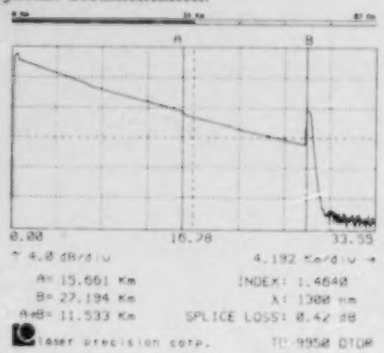

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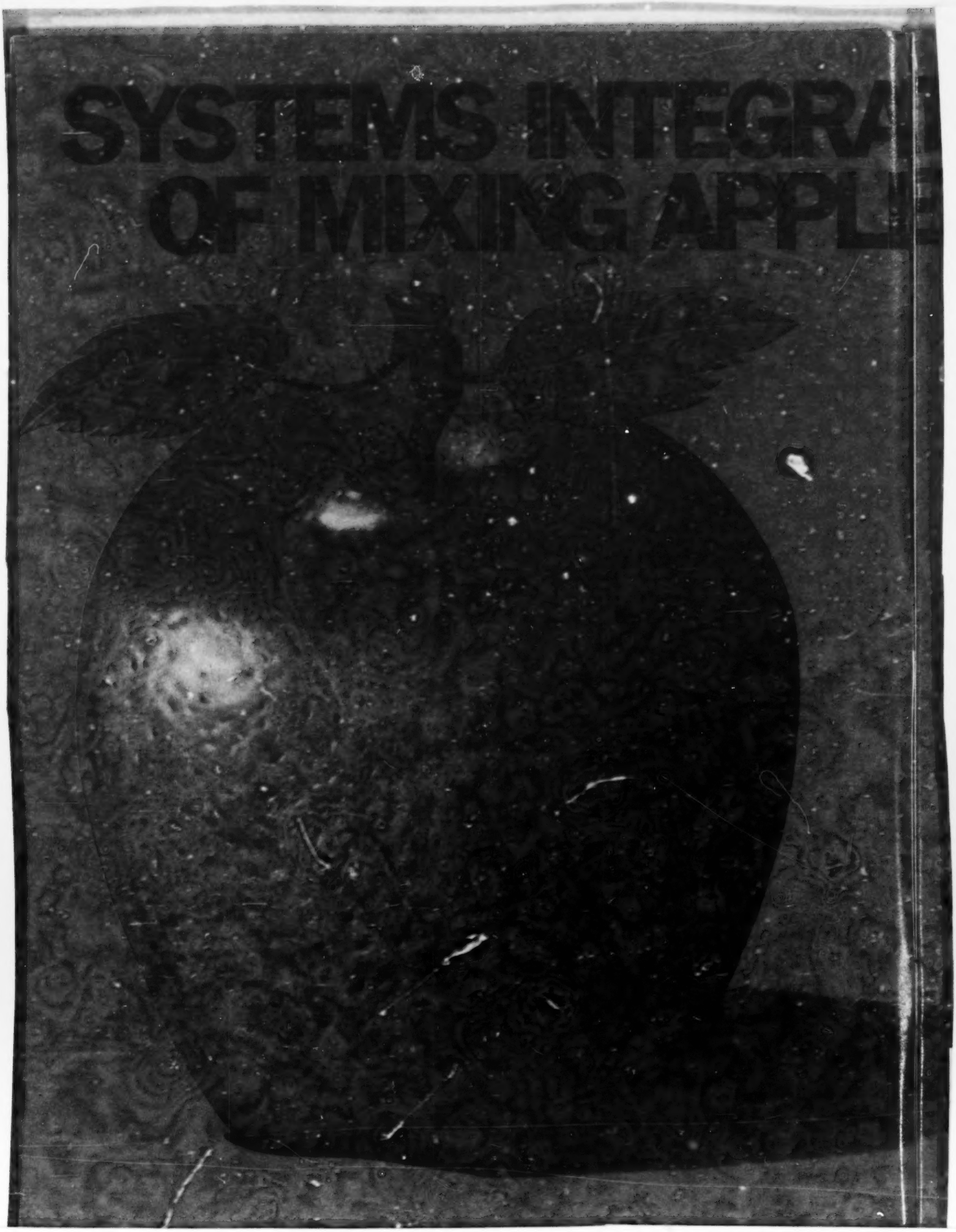
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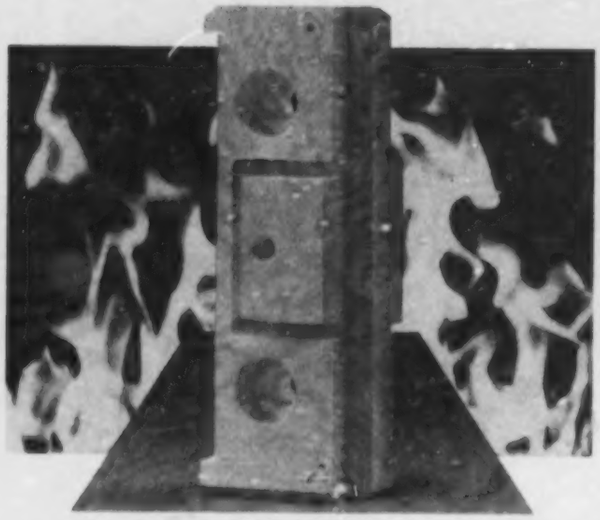

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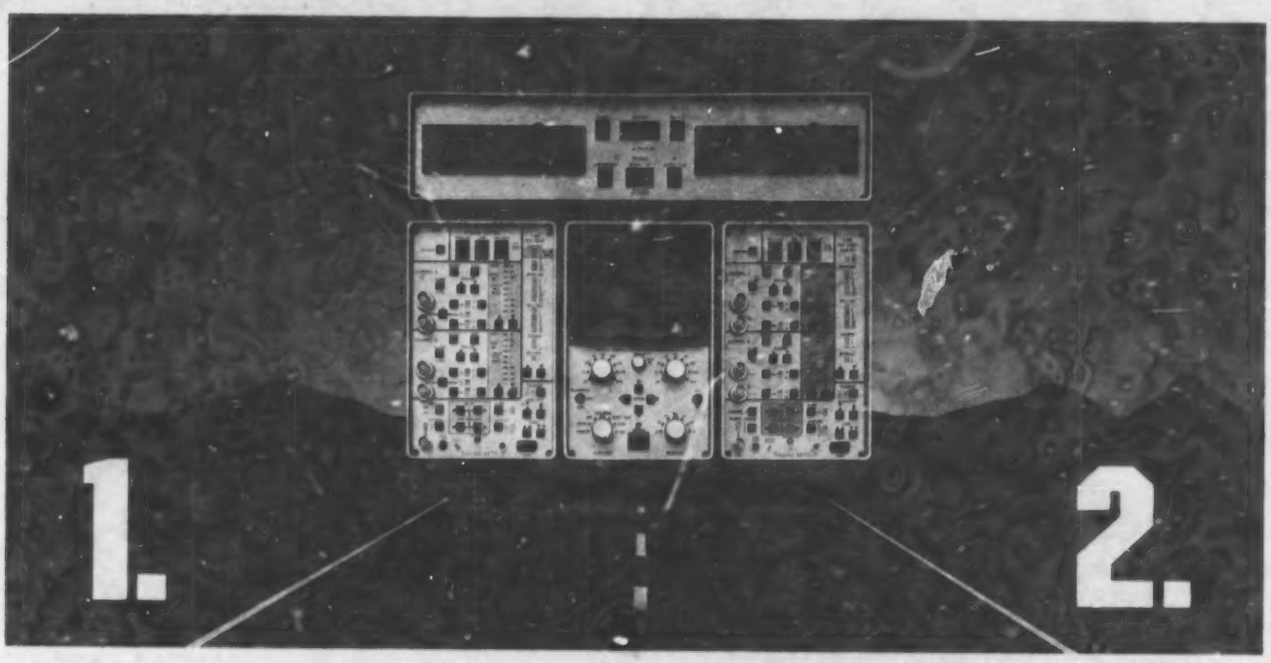
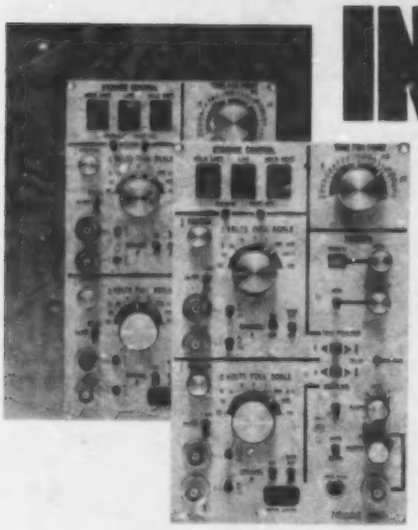


TWO DIGITAL SCOPES IN ONE.



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Editorial Notebook

As regular readers of NASA Tech Briefs will have gathered, this is no ordinary issue of NTB. Our research has shown that well over 70% of our readers buy or specify computer hardware and/or software. The number of readers who use computers on a regular basis is even higher than that.

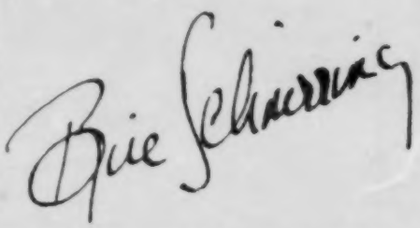
Moreover, our readership is literally growing daily, and more than half of the people who now receive NTB did not receive it two years ago. A number of these newer readers have mentioned that they really like the magazine, but also wonder what they've been missing. Add to that the fact that computer-related editorial material ranks high on the interest list in every survey we've taken, stir in the general interest in what NASA's doing on the computer front, and you have the reason we decided to publish this special issue, NTB's Computer Previews '87.

We've tried to present a taste of what's going on at NASA vis a vis computers. We've reprinted a number of what have historically been the most requested and/or most important software briefs, which I've called, for want of a better term, Golden Oldies. We've got a feature on COSMIC, the great NASA software library, and another on AI, as well as articles on other computer-related subjects. We've also added an area where suppliers are able to give you a little information about what they have to offer. You will also soon note that there are no tech briefs that are not computer-related.

It's a radical departure for us, and we'd like to get your reaction to our doing a once-a-year or occasional issue like this. I do want everyone to understand that this issue in no way supplants our regular publication of NASA Tech Briefs. We were scheduled to publish but six regular issues of NTB this year, all of which you have already received. This issue is, then, "value added"...or at least that is how we hope you will perceive it.

In 1987 we plan to publish 10 regular issues of NTB. Those of you who have been regular readers for some time will remember that when we first commercialized NTB in 1985, we published quarterly. Provided that all goes well, and we see no reason why it should not, we should become a monthly publication in 1988. I cannot reiterate enough that this is our magazine. Let us know what you do and don't like about it. We keep pushing the envelope. Help us, if you will.

How? Keep the cards and letters coming. □



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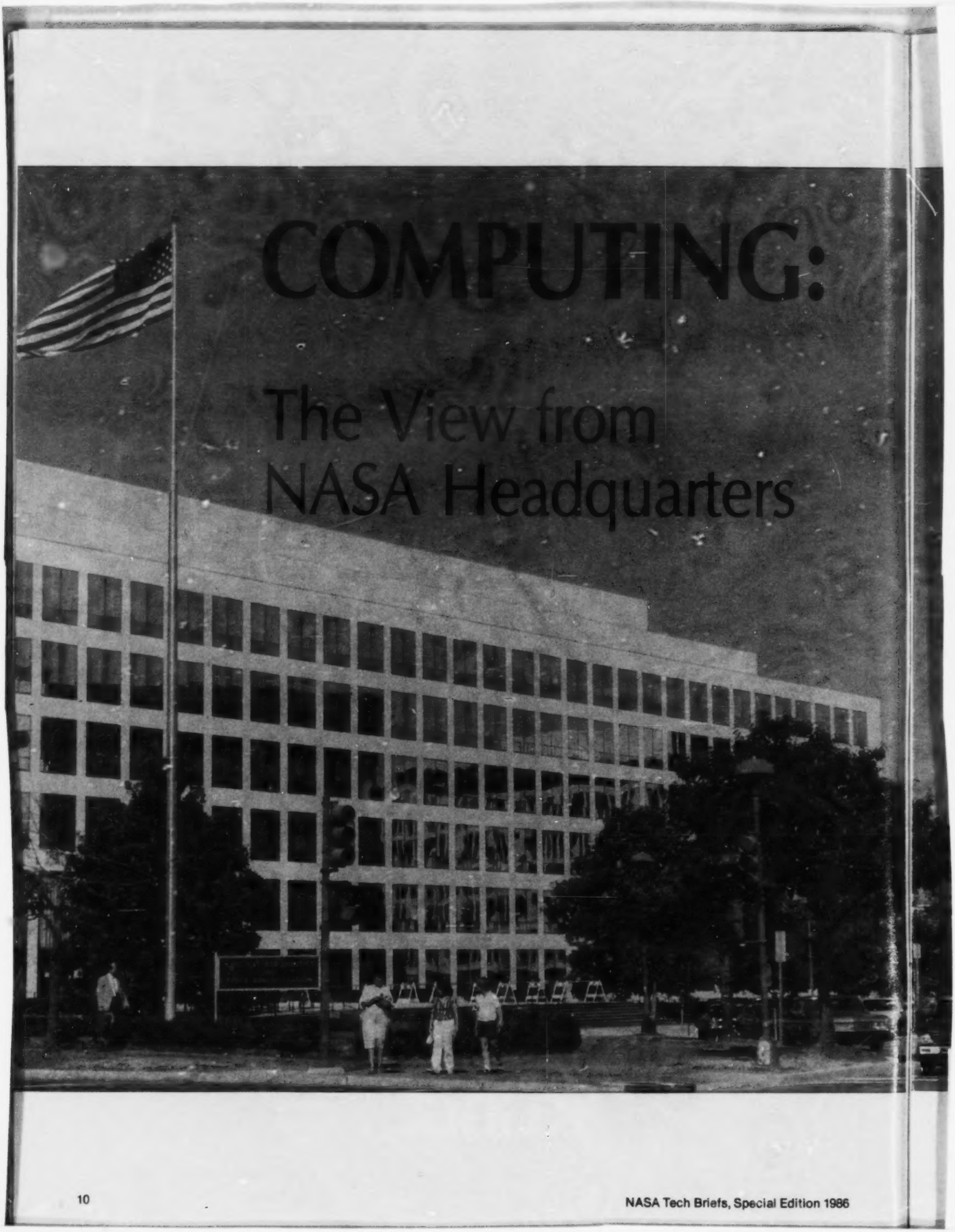
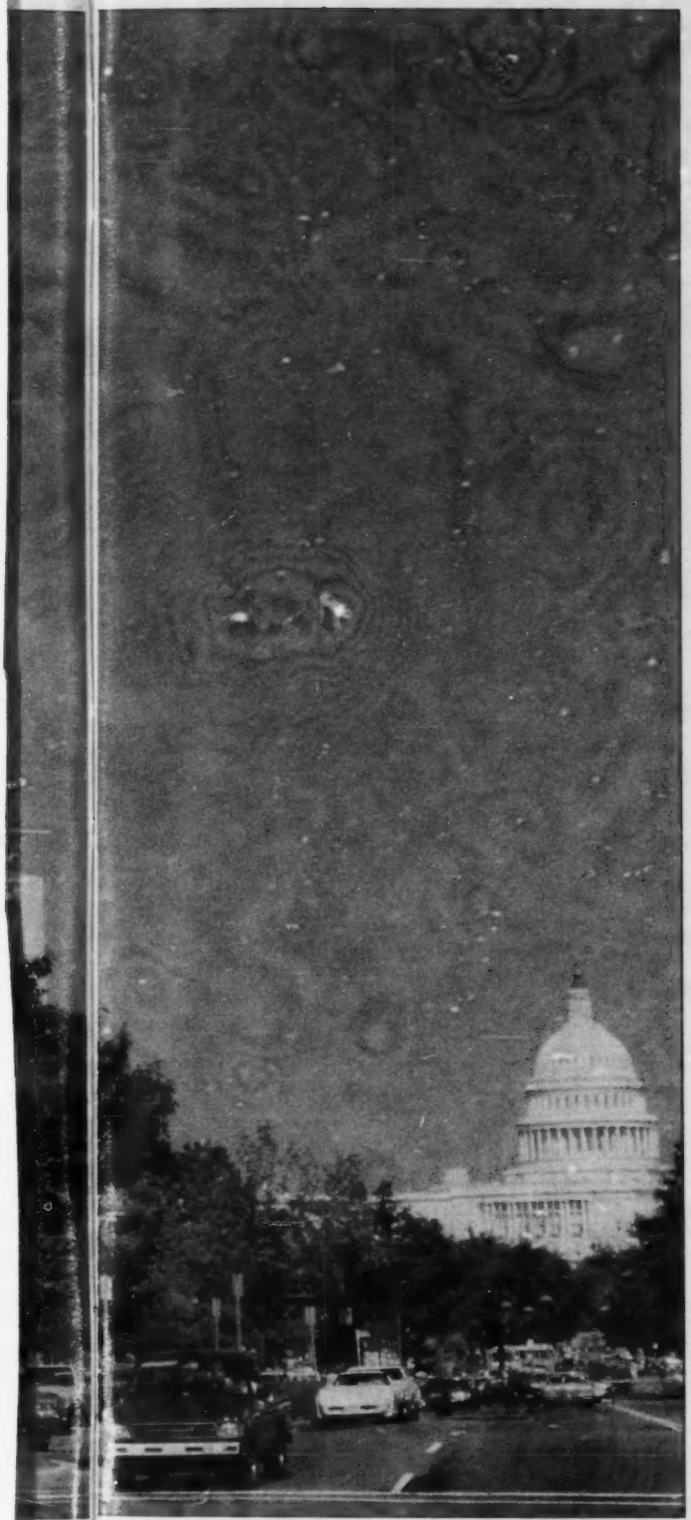


COMPUTING:

The View from NASA Headquarters



The National Aeronautics and Space Administration Headquarters, located between the Washington Monument and the Capitol, determines Agency programs and projects, establishes management policies, and reviews and analyzes all phases of the aerospace program.

Make up a list of the leading contributors to America's growth in high technology and NASA would surely be among the top entries. For more than 25 years, NASA's requirements for its manned and unmanned space programs have inspired major breakthroughs in engineering, science and medicine. NASA's programs have nurtured astounding growth in a number of industries, especially in companies involved in the development, use and manufacture of computers.

Today, through the leadership of NASA Headquarters in Washington, D.C., NASA continues to break new ground in the use of computers to solve difficult technical problems in disciplines related to space and aeronautics. NASA also devotes a significant portion of its resources to develop methods to make computer software more reliable, cost-effective and reusable, and to increase the overall productivity of the agency through the use of computers. All of these activities are a part of NASA's mission to "conduct aeronautical and space activities for peaceful purposes for the benefit of all mankind," as prescribed by the National Aeronautics and Space Act of 1958.

It's difficult to think about NASA's high technology programs without acknowledging the central role that computers play in many of them. It's just as hard to imagine a time when NASA did not depend on computers to accomplish the goals of its research and space programs. Yet Project Mercury, America's first manned space program, was in progress years before the first pocket calculator was sold. Space flight without an on-board computer? There was no computer aboard the single occupant Mercury spacecraft. Today the Space Shuttle relies on five on-board computers to handle all phases of its flight, from ascent to reentry. NASA's use of computers in other areas has also changed dramatically. The agency is developing new computational capabilities to study aerodynamical phenomena related to vehicle design. NASA is conducting research in electronics, computer science, artificial intelligence, and robotics for increased use of automation, improved information processing and advanced communications systems.

All of this work is planned, directed and coordinated by NASA Headquarters through a number of program offices. The operational aspects of NASA's work in aerodynamics and space are performed at its field centers throughout the country. Each installation has a specifically described mission, with related tasks, and is allocated the resources for their accomplishment.

Some of the major computing activities at the NASA Centers are centered around theoretical analysis, computer-aided design/analysis, real-time flight simulation, and test data acquisition and reduction.

Theoretical analysis and simulation in the disciplines of fluid mechanics, avionics, acoustics, structures, and atmospheric model- ►

ing depends heavily on the use of ultra high speed, large memory, advanced scientific computer systems. To meet this demand, NASA Headquarters is planning for a variety of computational facilities containing state-of-the-art supercomputers.

In a major bid to advance the frontiers of computational analysis, NASA is developing the Numerical Aerodynamic Simulation (NAS) system. Its goal is to provide a testbed for developing new techniques to tackle complex computational problems. The NAS system will consist of a network of high speed processors anchored by the CRAY-2 supercomputer.

NASA Headquarters' emphasis on research productivity is increasing the use of computer-aided design and analysis tools. These tools will allow engineers to evaluate and refine promising advanced aircraft and space vehicle configurations from concept to detailed design while minimizing the need for expensive model design and laboratory testing.

Real-time flight simulation is accelerating the development of new aeronautical controls for aerospace vehicles. Simulation uses mathematical models of vehicle aerodynamics, controls, propulsion systems, structures, avionics, and environmental characteristics. Computer controlled displays and kinesthetic cues provide pilots with a realistic, ground-based cockpit in an environment approaching that of actual flight.

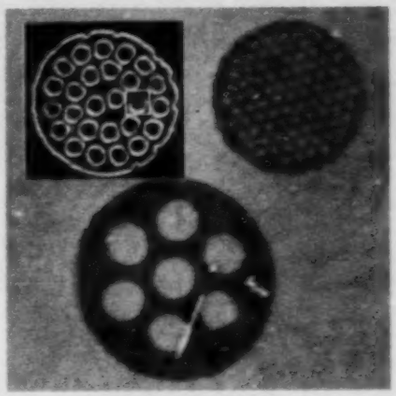
Experimental data collection and reduction is a fundamental part of most research and development activities. Wind tunnels, airborne experiments and remote sensing systems generate enormous amounts of data that often must be analyzed in real-time in order to control the experiment. As experiments increase in complexity and sophistication, significant increases in speed, reliability, and complexity of the data acquisition and reduction systems are required.

Two important computer related Headquarters programs, the Software Management and Assurance Program and AIM, deal with reliability and productivity. While not as well publicized as NASA's space accomplishments, these two programs are confronting challenging problems whose solutions are vital to the ability of NASA to carry out its overall mission.

The Software Management and Assurance Program (SMAP) is concerned with assessing and improving software practices used on major NASA projects. The program is directed by the Office of the Chief Engineer at Headquarters and concentrates on software policy, software engineering tools and techniques, human resources and information exchange.

NASA's Automated Information Management (AIM) Council is trying to increase the productivity of administrative personnel and to automate the administrative functions for the entire agency. Dr. C. Howard Robins, in the Office of Management at Headquarters, is the AIM Council Chairman. According to Robins, "The percentage of NASA's budget being spent on information systems has at least doubled in the last five years. Information systems now account for 10% of NASA's budget." In listing the conditions contributing to rising costs, Robins indicates that "the growing cost of software and maintenance has more than eaten up the difference in hardware cost reductions." Robins is optimistic, though, that the AIM Program can help to reduce these costs and allow the agency to make better use of its precious resources.

These are just a few of the many research and development projects that NASA Headquarters is currently planning, directing and participating in. Further details on these and other projects appear in articles elsewhere in this issue. □



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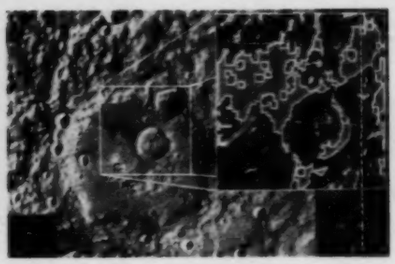

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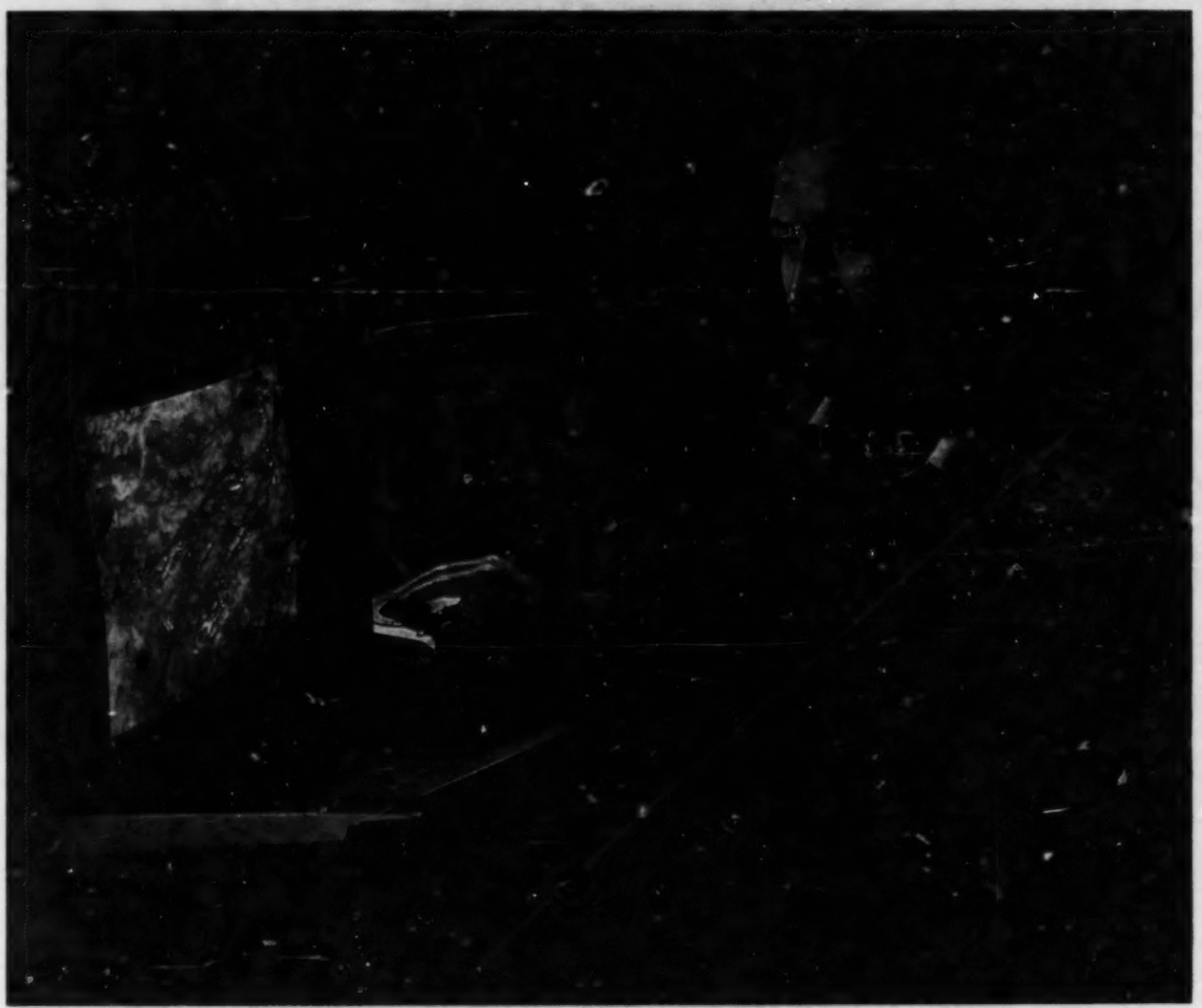


Using the Earth Resources Laboratory Applications Software, a technician computer-enhances a Landsat image to include geographic coordinates.

Taking 98.9 minutes between sunrises, a Landsat satellite orbits at an altitude of 438 miles. Along each orbital path, the Thematic Mapper (TM) sensor scans an eight million acre swath with a resolution or cell size 30 meters square. Complete coverage of the earth is achieved in 233 orbits; sites receive repeat coverage every 16 days. The TM sensor measures and records blue to mid-infared reflected light energy and emitted thermal energy.

Each cell, equivalent to a pixel on a digital display, contains seven raw data values which must be manipulated to produce useful images. The Earth Resources Laboratory Applications Software (ELAS), developed at NASA's National Space Technology Laboratories, was especially designed to analyze and process this multispectral digital data.

Because ELAS processes digitized

ELAS software is used to interpret Mars images transmitted by the Viking orbiter.

data, it has applications that range far beyond interpreting Landsat information: Aircraft-acquired scanner data, digitized topographic data, soil types and rainfall information; any information that can be stored in digitized form. As an integrated image processing and data base maintenance system, ELAS offers the remotely sensed data user a wide range of easy to use capabilities in the areas of land cover analysis.

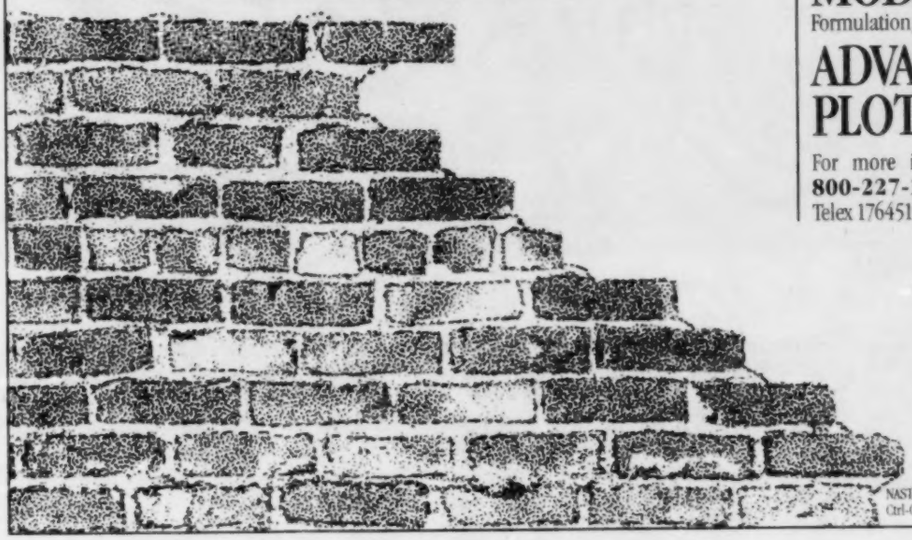
Composed of 300 separate executable programs, or application modules, and an operating subsystem, ELAS is meant to be as variable as possible. For easy changing from one application to another, the operating system handles all input/output functions, system control functions, and applications module swapping when necessary. The versatile operating subsystem and the available application modules allow users to perform an unlimited variety of land cover analyses, as well as data base construction and manipulation.

ELAS User Group

In 1983 the NSTL Earth Resources Laboratory (ERL), which authored the original ELAS software and documentation, helped form the worldwide ELAS Users Group. The Group disseminates information concerning the ELAS package, and assists users who are just beginning to implement the software.

Annual meetings are held at NSTL, where improvements continue to be devised and added to the ELAS software. Providing a forum for the user community to exchange information on any aspect of the program, the meeting is an opportunity for synergism of the finest kind. According to Sid Whitley, Deputy Director of the ERL, "We've found that if a geologist develops something, the agronomists or the hydrologists or the geographers are looking eagerly over his shoulder; they try it to see what utility it has for their own applications. It makes little difference what the algorithm was developed for; it finds its way into the other disciplines as well."

An engineer should use a design foundation, not build one.



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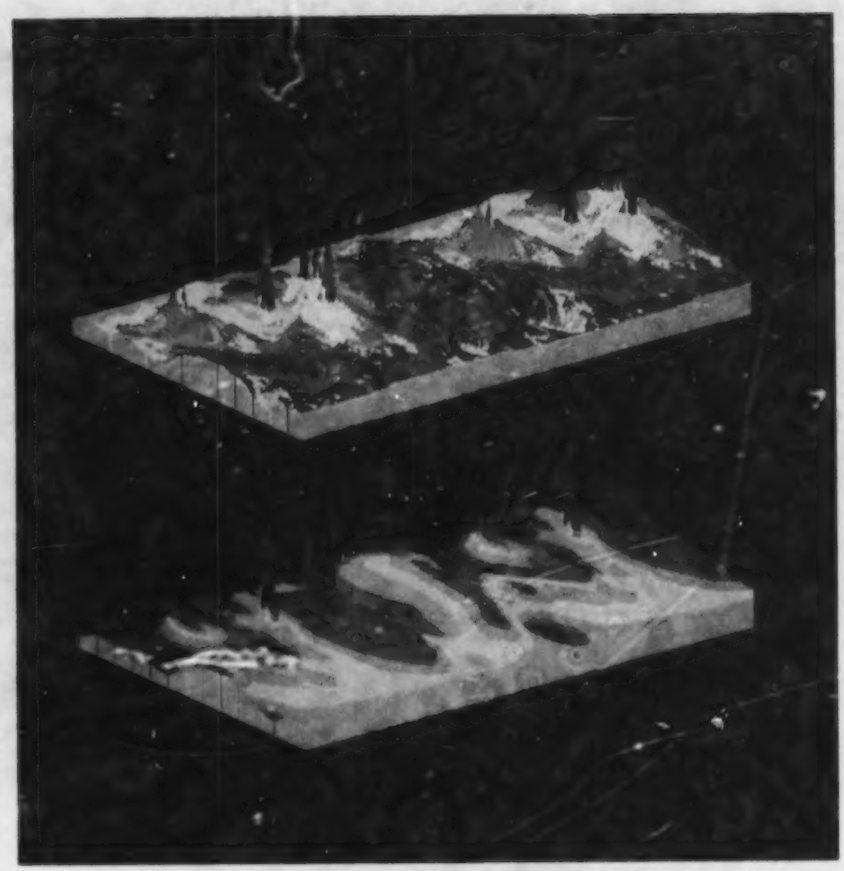
Whitley sees ELAS with continually improving and increasing capabilities, mentioning that ERL personnel are "always improving documentation, based on user feedback." Software additions are made frequently, a result of on-going research and development at ERL.

With a well structured and enthusiastic user group, and a highly supportive central clearing house for software improvements, this versatile program is a real winner, a fact supported by its longevity. To learn more about the Earth Resources Laboratory Applications Software, or to obtain a copy, contact NASA's COSMIC, mentioned on page 43 of this issue. □



At the Center for Earth and Planetary Studies in the Smithsonian Institution's National Air and Space Museum, Dr. Thomas R. Watters, a research geologist, makes use of the Earth Resources Laboratory Applications Software for planetary studies. With "Mars Consortium Data" garnered from the Viking orbiter, Dr. Watters examines such information as topography, thermal data and albedo, using a variety of classification schemes afforded by the software. Here are two three-dimensional perspective views of the Mars topography. The upper perspective is color coded with the geologic units of Mars, while the lower is color coded topography.

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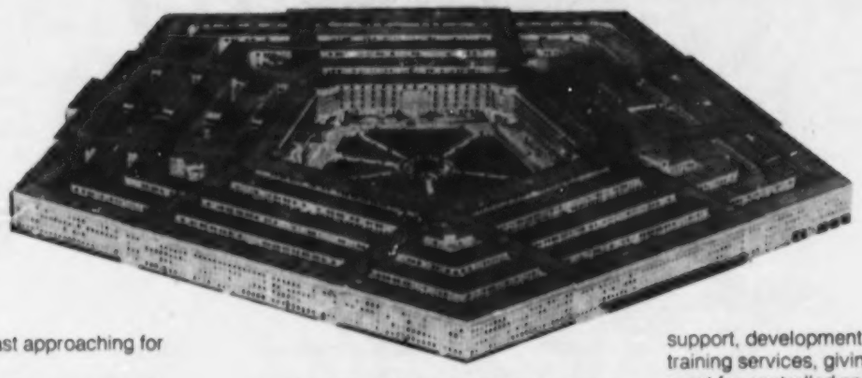

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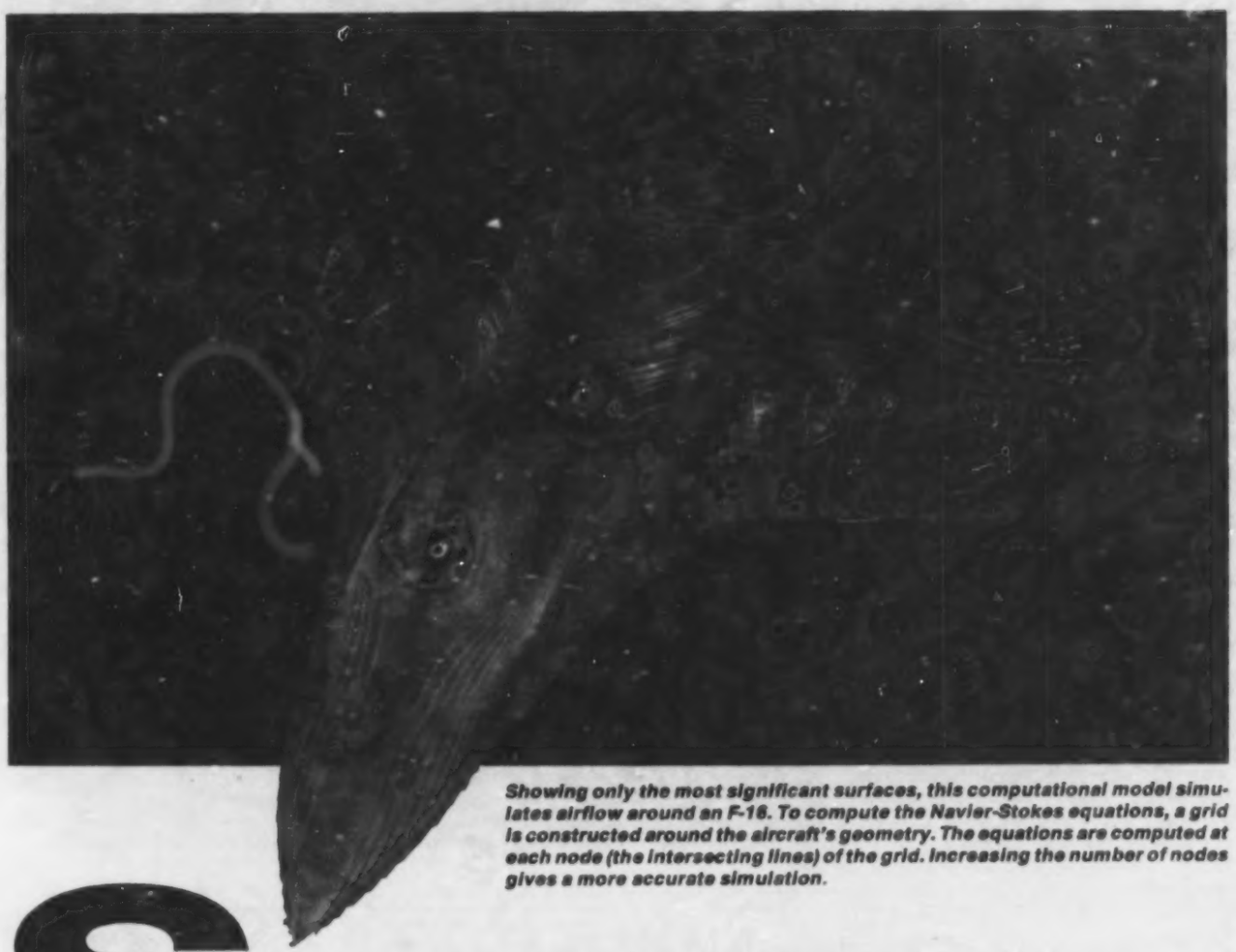

Showing only the most significant surfaces, this computational model simulates airflow around an F-16. To compute the Navier-Stokes equations, a grid is constructed around the aircraft's geometry. The equations are computed at each node (the intersecting lines) of the grid. Increasing the number of nodes gives a more accurate simulation.

SUPERCOMPUTING AT AMES RESEARCH CENTER

A Cray-2, Serial Number 2, the most powerful supercomputer in the world, sits in Building 233A at the Ames Research Center. The Cray-2 cornerstones the Numerical Aerodynamic Simulation (NAS) Program, which serves as a national supercomputing facility. This acquisition represents the first major milestone of the NAS, forming the initial operating configuration of the NAS Processing System Network.

The genesis of the NAS program goes back to the middle seventies when Ames computational fluid dynamics researchers realized more advanced supercomputers were needed to solve their fluid physics equations. Computational Fluid Dynamics (CFD), used in aerospace vehicle design, combines fluid physics, computer science and applied mathematics. With wind tunnel tests, CFD is an important tool for understanding the forces acting on aerospace craft and their engines.

The researchers defined the future NAS as an ongoing, continuously upgraded program. Three objectives were set:

1) The NAS program would provide a computational capability to ensure leadership in CFD and related disciplines, available to NASA, Department of Defense, other government organizations, industry and universities;
2) Continuous hardware and software upgrades would maintain state-of-the-art facilities;
3) The NAS program would provide a strong research tool for NASA's office of Aeronautics and Space Technology.

NAS has been in "Initial Operating Configuration" since July, 1986, when the Cray went on-line at Ames. With ►

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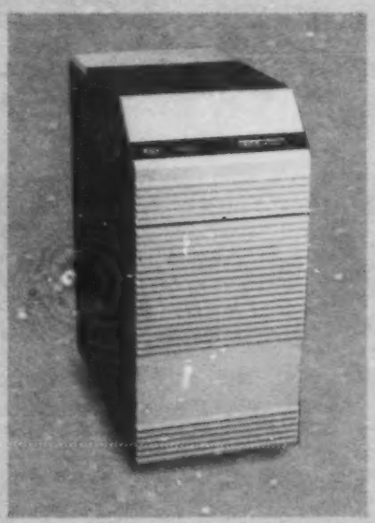

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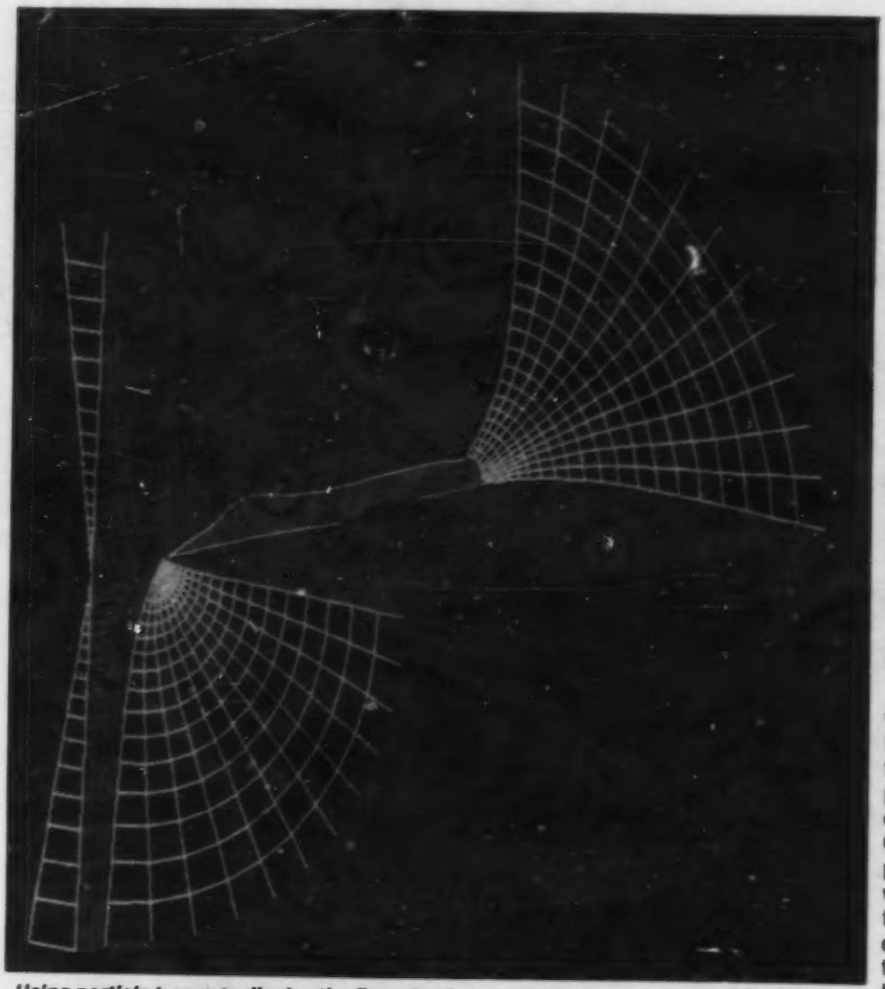

Using particle traces to display the flow physics, vortical patterns created by the strake and leading edge of an F-16 are shown. The particles are color mapped according to their elevation above the wing, providing a three-dimensional view of the vortical interactions.

an upcoming move to a dedicated facility and subsequent testing, the NAS will begin full operations in March, 1987. The NAS Cray has a sustained computational rate of 250 million floating-point operations per second (Mflops), as opposed to a burst speed of approximately two billion Mflops. Supercomputer qualities include a 256 million-word central memory and a 4.1 nanosecond clock-cycle time. The system configuration includes two Amdahl 5840 computers, four VAX 11/780, and 30 Silicon Graphics IRIS workstations. Frank R. Bailey, Manager of the NAS Projects Office, explains one of the benefits of the configuration: "An important thing about the system is that all these computers are networked together, they all use the Unix operating environment."

The Advantages of Power

The degree of computing power inherent in the NAS has proven its worth. Says Bailey, "We've demonstrated the great advantage of a very large memory capacity supercomputer. NAS users are able to approach problems they've not been able to consider before."

Bailey mentions that the NAS is the first opportunity to exploit high performance graphics workstations and supercomputers operating in a cooperative, symbiotic manner. This allows task division between the supercomputer and workstation so that each is performing its function optimally. For example, large scale calculations on a complex model such as viscous flows around an F-16 are computed on the Cray-2. The data from that calculation can be abstracted for display on the workstation.

By rapidly sending results from the Cray to the workstations, which themselves can do interactive graphics manipulation, the system can display three dimensional perspective graphics. The rapid response time gives users immediate feedback to the results of their calculations.

A nationally available resource, the NAS is on-line through a sophisticated set of communications devices, including NASA's Program Support Communication Network, (PSCN). Through NASnet, connecting remote Ethernets to the Ames Ethernet, remote users have "all the capabilities someone locally in the NAS facility would have," according to Bailey. NAS also accesses MILnet and ARPAnet, run by the Defense Communications Agency. Bailey's goal is to be able to access all the available networking within the government infrastructure.

One of the most striking examples of this pioneering remote access technology is the use of the "Dialup 56 kilobit Service." This enables remote users to connect to a NASA PSCN gateway over commercial telephone lines. Connected to NAS at a relatively high bandwidth, users can simply hang up when they're through.

In the Future

Staying at the cutting edge of advanced scientific computing systems is a primary NAS goal. Bailey's acquisition plan includes a sequential improvement of the High Speed Processors (HSP) in the NAS. HSP-1, the CRAY-2, is the first of the high speed processors. The next generation HSPs will be integrated to the facility this fiscal year, giving it two HSPs, one each of the first and second generation. HSP-2 will be able to perform 1000 Mflops, and should have a central memory capacity of one billion words. Bailey foresees a performance increase of four to five times with each generation.

A decade of study has resulted in a state of the art supercomputing facility at NASA's Ames Research Center. The recent acquisition of the Cray-2 represents a major milestone in the NAS program. Intended to advance aerospace research and development through the field of computational fluid dynamics, the NAS includes the ability to support supercomputer-generated large-scale aerodynamic flow simulations with powerful workstations, high-resolution graphics, and high-bandwidth remote communication links to nationwide remote sites. □

Any researcher involved in U.S. industry, academia or government aerospace programs can apply for access to NAS resources. For the operation period beginning in March 1987, applications are available from Leslie Chow, User Interface Manager, NASA Systems Division, Mail Stop 233-1, NASA Ames Research Center, 94035. Potential users must demonstrate a requirement for the unique capabilities offered by the NAS.

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The Hypercube—

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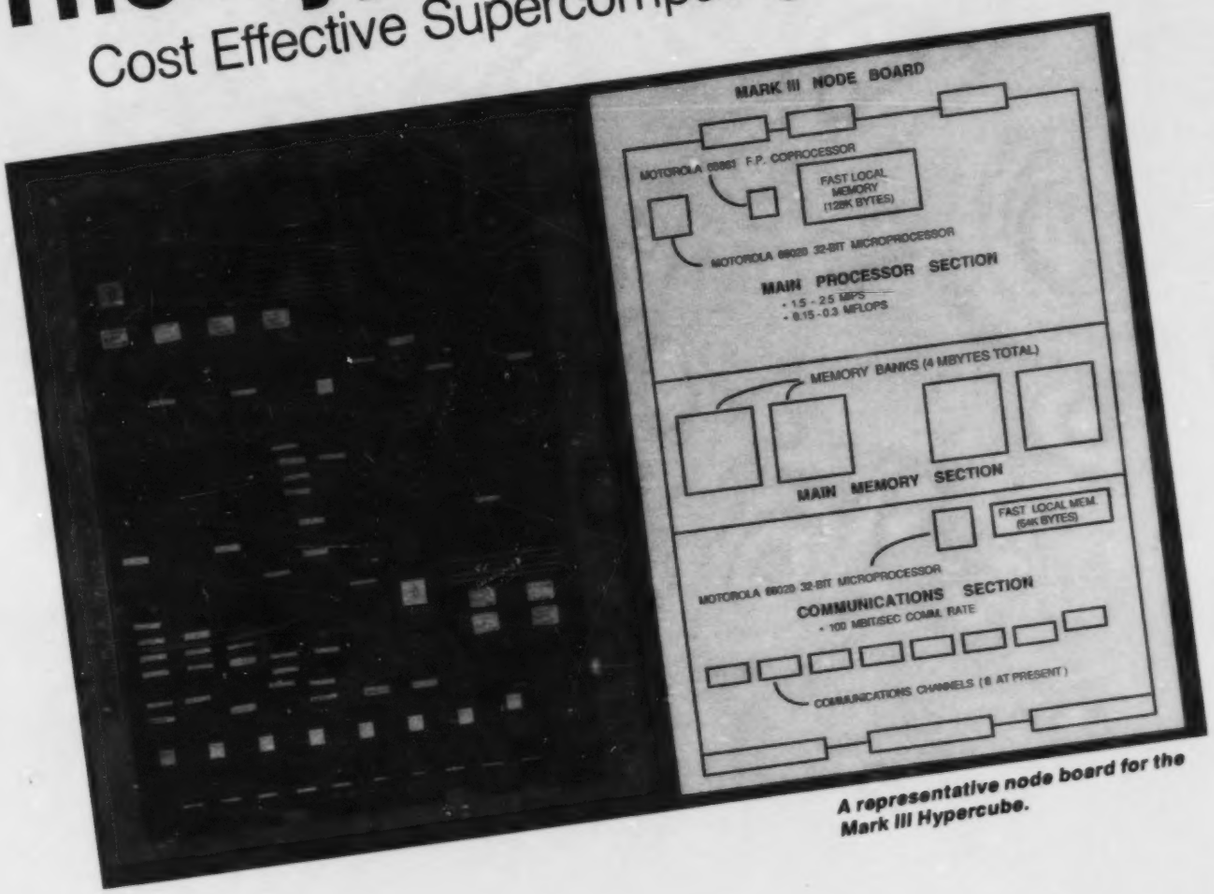
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A representative node board for the Mark III Hypercube.

A new and exciting area of research at the Jet Propulsion Laboratory's (JPL) Advanced Microelectronics Program (AMP) involves the investigation and development of concurrent computers to attack computationally intense problems. The power promised by this type of computer can be applied not only to well-understood numerical applications, but also to the more complex problems that are found, for example, in expert systems and artificial intelligence.

It has been recognized for some time that substantial (i.e. order-of-magnitude) increases in the computing speed of future-generation computers will be attained only through the development of concurrent, or parallel, computation. Ultimately the various components within a single Von Neumann-type machine cannot communicate with each other at greater than the speed of light, a limit now being pressed (in Von Neumann machines instructions are carried out one after another, building in a basic limitation of processing speed). With VLSI technology providing almost mainframe computational performance in increasingly smaller packages, arraying a sufficiently large number of microprocessors can provide cost-effective, next-generation supercomputer performance.

Enter the Hypercube

One approach to concurrent computing is the Hypercube. In this configuration, a number of microprocessors are directly linked in an array containing 2^K processor-nodes, with each node connected to its K nearest neighbors. A K = 3 configuration is a normal cube, with eight concurrently operating computers. As K values increase, the configurations are nested and represent cubes in higher spatial dimensions, hence the name "hypercube."

Mark I and II

In 1981, the California Institute of Technology began investigating Hypercube architecture by constructing a first generation 64-node Hypercube, using the Intel 8086 16-bit microprocessor. Its demonstrated performance was about eight times that of the DEC VAX 11/780 supermini computer.

JPL became involved in 1983, designing and contructing the Mark II Hypercube, based on an enhanced Mark I design. Four 32-node Mark II machines and one seven dimensional, ►

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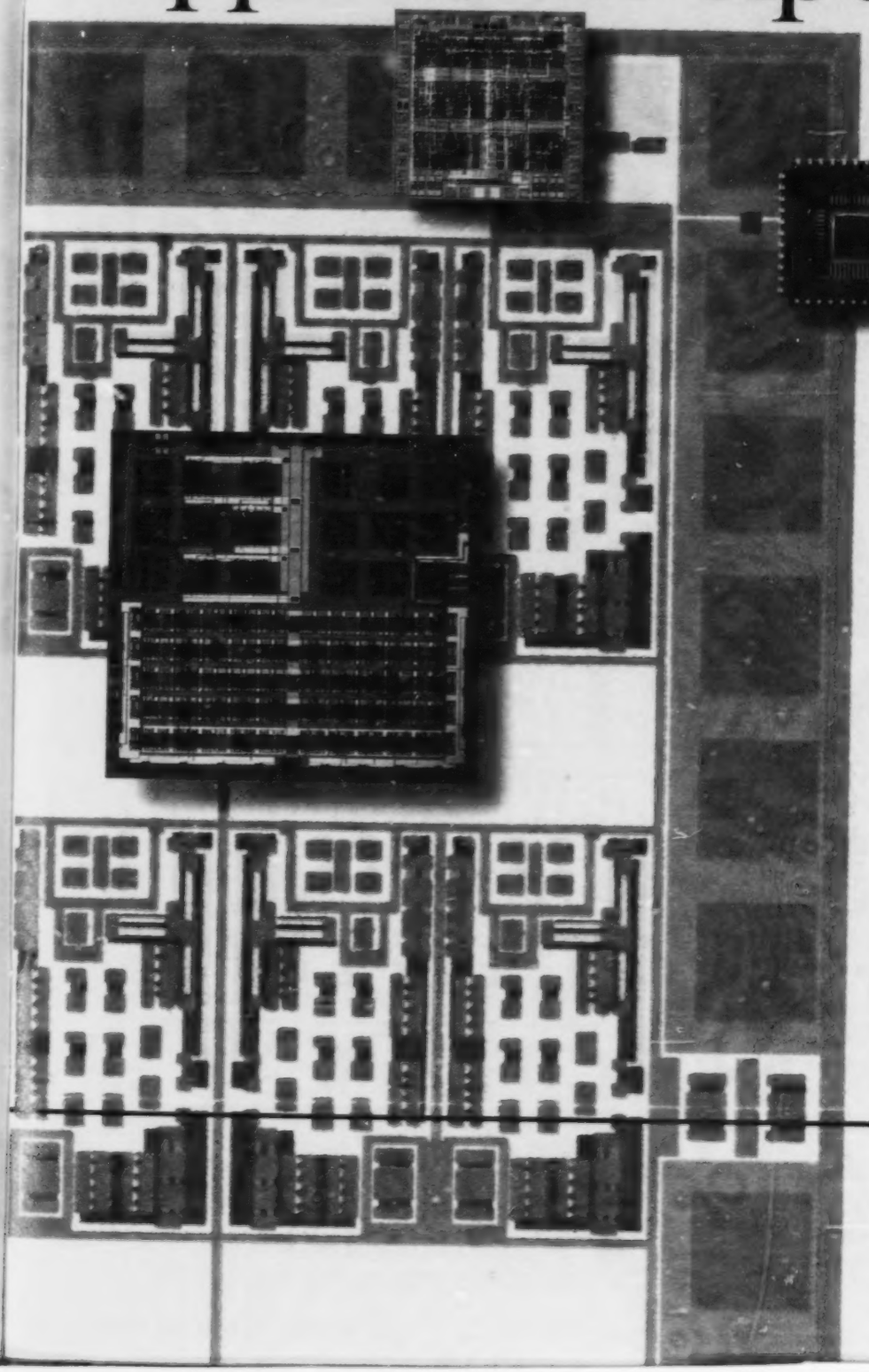

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This 32-node Mark III Hypercube has the computing power of 32 to 64 of the VAX 11/780 minicomputers.

128-node machine were constructed. The 128-node system has the performance of about 25 times the DEC VAX 11/780 supermini computer.

Mark III and IIIe

In 1986 the JPL Hypercube Research Project designed and built the Mark III concurrent computer, based on the Motorola MC68020 32-bit microprocessor. Two four-node systems and two 32-node systems serve as test beds for developing diagnostics and software. Each Mark III node has a performance of between one and two DEC VAX 11/780 computers. Mark IIIe nodes, being designed with Weitek Floating-Point Processor daughter boards, should have a capability of 10 MFlops per node. A concurrent computer assembled from 32 of these enhanced nodes should show performance in the range of a Cray-XMP supercomputer, at about 1/10th the cost. A 256-node system should perform equal to or better than the next generation Cray machines.

More and Better

In the quest for more powerful computers, the Hypercube Research Project participants have a fairly clear view of their crystal ball. Dave Rogstad, Principal Investigator at the Hypercube Project, doesn't see any theoretical design limitations to adding more nodes to a Hypercube architecture. Practical size could become a consideration, however. Says Rogstad, "What's likely to happen in the future is not that we would increase the number of nodes, or even worry about making the nodes physically smaller; what's more likely is that the nodes themselves will be made from much more powerful and faster chips."

Rogstad mentions some of Hypercube's selling points: "The main reason why Hypercube is considered to be more cost effective is that we're using commercial, off-the-shelf microprocessor components. They tend to be a factor of 10 cheaper than the kind of components that goes into making Crays."

Having designed and built powerful Hypercube architectures, Rogstad and others participating in the Hypercube Project turned their attention to proving the utility of their design. A cost effective computer loses its worth if it can't easily be programmed, but Rogstad and his team have proven otherwise. 'We have demonstrated that you can hook up hundreds of microprocessors and realistically and easily program them on intensive computing problems, the kind of problems you buy Crays to attack."

Because scientific and engineering problems and their solutions are often parallel as well as sequential, the distributed processing inherent in Hypercube architectures offers ideal solutions. Using off-the-shelf components, Hypercubes promise supercomputer performance at a fraction of the cost. □

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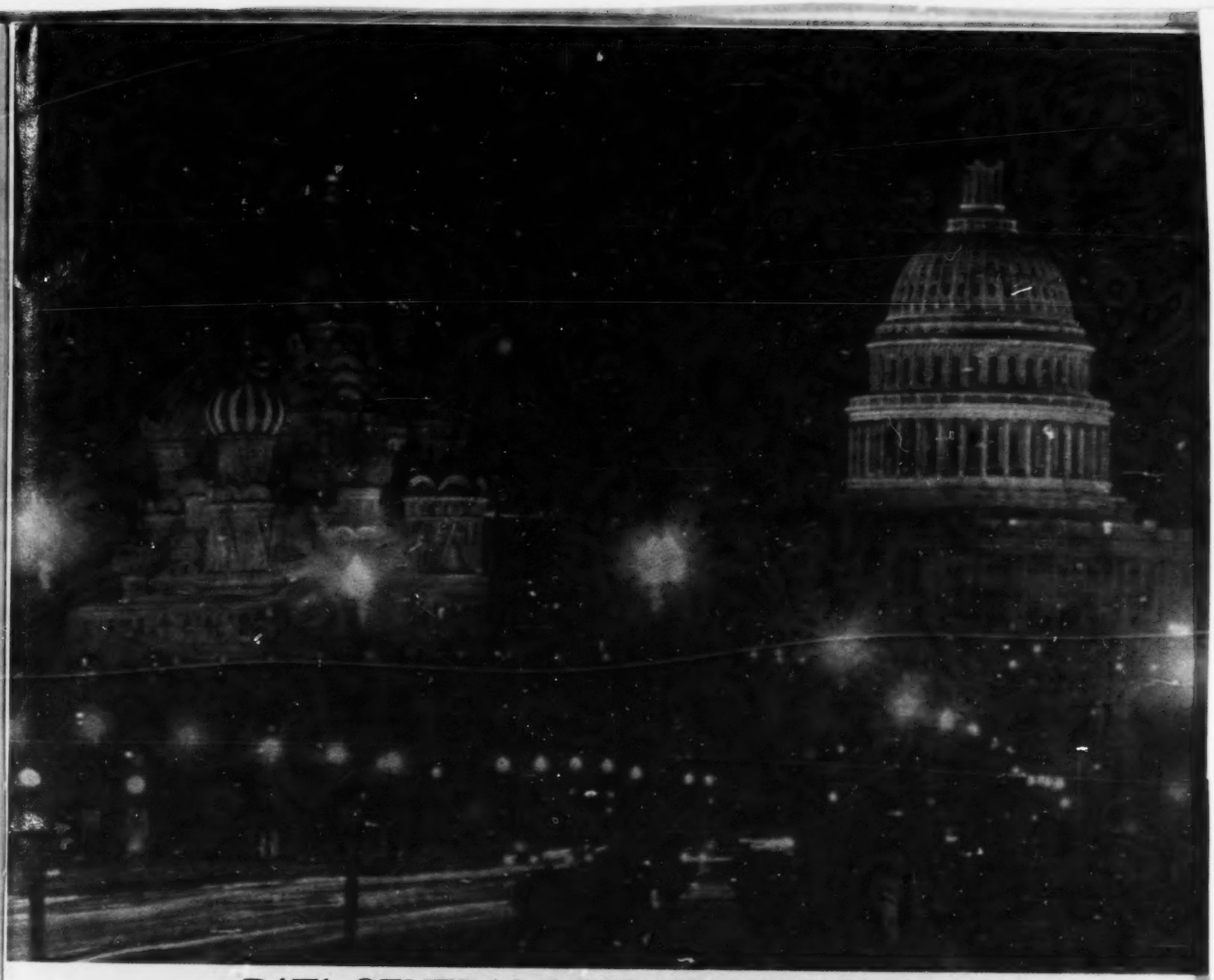

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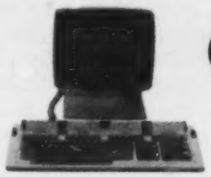

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At Kennedy Space Center, launch preparations include staying aware of weather conditions. The Thunderstorm Weather Forecasting Expert System project will help predict severe events.

Artificial Intelligence:

Rendezvous with NASA

Once the near exclusive domain of academia, Artificial Intelligence (AI) has begun to make its mark in a number of areas in the scientific and business communities. The development of practical AI applications has been slow for decades, but new, powerful and less expensive computers have helped move AI and expert systems from the confines of the laboratory into the real world.

Artificial intelligence generally refers to the use of computers to supplement or replace human reasoning in decision making processes. Dr. Henry Lum of NASA's Ames Research Center explains that "AI is a very broad term; taken literally it tends to create a great deal of confusion about what AI actually is all about. The term 'expert system' is usually substituted when speaking to most audiences."

Artificial Intelligence now gets its share of headlines, but that hasn't always been the case. Only a few years ago, most of us assumed that AI referred to the crossword puzzle entry for a three-toed sloth. Artificial Intelligence sounded like something that football coaches invoked at halftime to rally the troops. Suffice to say that AI had a recognition problem. More importantly, the vocabulary of AI probably kept a large number of potential users at arm's length; AI is a world populated by terms such as first order predicate logic, inference engines and instantiation. Peering into this world, NASA saw the potential for using expert systems to solve difficult problems related to space flight and the development of the Space Station. A sampling of NASA's current expert systems projects reveals that NASA is making a broad commitment to AI.

One of NASA's expert systems projects, dealing with near term precision weather forecasting, seems to have great potential for further increasing safety in commercial airline flights. Other ambitious NASA AI projects involve with expert planning, payload integration, and machine learning.

Expert System Weather Forecasting

Space Shuttle operational weather forecasting at the Kennedy Space Center (KSC) is provided by the U.S. Air Force for the Cape Canaveral Forecast Facility. Forecasters have tours of duty ranging from two to four years. The expertise that they develop in predicting weather at this coast location leaves when their tour of duty ends. Operational forecasting is further complicated by the volume of data available from conventional weather data sources and from numerous specialized instrumentation systems ►

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While constructing short term weather forecasts it is difficult to handle large volumes of data and determine which data sources are appropriate to use.

In this context, the Thunderstorm Weather Forecasting Expert System (TWFES) project is developing a weather forecasting aid that captures the individual expertise of forecasters, and also provides a tool for weather event anticipation. Art Beller, manager of the TWFES project, expects that "the system is not going to replace the individual forecaster; it's going to assist him by focussing his attention on anticipating certain events and telling him where to look for supporting data." The initial emphasis on thunderstorm prediction is due to the fact that shuttle operations are strongly affected by lightning near the operational areas. Beller explains that "At KSC there's a thunderstorm everyday during the summer. Patterns begin to emerge; if there's a strong sea breeze off the coast, there probably will be no thunderstorms over the Cape; they'll be inland. Prevailing winds from the west give rise to other scenarios. The idea is to have a machine reason from the scenarios and then assist in the weather prediction process."

The system, which is still in the proof-of-concept phase, runs on a Symbolics 3640 and has a hybrid architecture utilizing both Zetalisp and the Automated Reasoning Tool. The prototype will identify and elaborate additional test scenarios, improve the user interface, and finalize the data interfaces. Beller hopes to add winter thunderstorms to the list of scenarios. "They're especially interesting because they usually have lightning, wind, and precipitation—possibly hail—all of which strongly affect shuttle launch operations." Current plans envision moving the TWFES into the operational setting of the Cape Canaveral Forecast Facility in 1988.

Payload Integration and Checkout

The Spacelab and Experiments Division of Payload Operations at the Kennedy Space Center has developed a real time data distribution network for use in the integration and checkout of scientific payloads prior to their launch on the Space Shuttle. The Smart Processing of Real Time Telemetry (SPORT) project merges high speed Symbolic Lisp Processors and personal computers to existing payload checkout equipment via a 10 Mbit/sec local area network. The SPORT system was first used during level IV testing of the ASTRO-1 SPACELAB payload.

The backbone of the SPORT system is a local area network following the IEEE-802.3 network standard known as Ethernet. Payload checkout equipment is attached to the network via network control processors. These processors encapsulate telemetry information into SPORT protocol packets for routing via DARPA's Standard Internet protocol and the Transaction Control Protocols. Network application processors then remove these packets for use by applications programs.

Two classes of machines are used as Network Applications Processors; IBM PC/AT's for slower applications and Symbolic 3670's for high speed applications. The PC's low level interface routines are written in 8086 assembly language and Lattice C, while the high level data analysis portions are coded in Golden Common Lisp. The high speed applications programs are written in Symbolics Common Lisp and the Automated Reasoning Tool from Inference Corporation.

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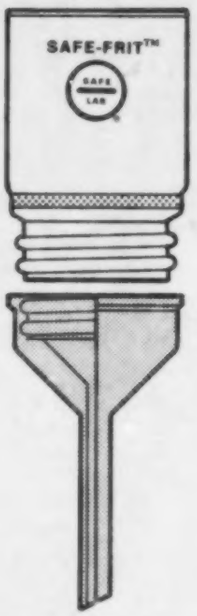

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in support areas, payload elements begin an assembly-line-like process that brings them together to form a compatible, functioning payload unit. Each phase of integration—experiment integration and Spacelab integration—results in a progressively more complete, functional flight payload. Planning and scheduling is an important part of this process, and two expert systems are being developed to enhance existing capabilities: the Expert Mission Planning and Replanning Scheduling System (EMPRESS) and the Planning Network (PLANNET). Eventually the systems may be integrated.

Using the same tools and problem-solving heuristics (rules) as a KSC planning and scheduling expert, EMPRESS will construct and maintain mission schedules. EMPRESS, developed by NASA-KSC and the MITRE Corporation of Bedford, MA, will support schedule planning by defining the time, resources, and task requirements associated with processing a Space Shuttle. EMPRESS will also help the planner with unanticipated schedule changes.

The principal objective of PLANNET (developed by McDonnell Douglas Astronautics-KSC with initial support from Georgia Tech's Engineering Experiment Station), was to demonstrate the feasibility and application of expert system technology to the problem of daily or longer term planning and rescheduling activities, including facility and resource utilization. The initial demonstration addressed only a subset of the planning and scheduling activities, but continuing work will expand the prototype system to make it more realistic.

Machine Learning and Control

As part of KSC's Knowledge-Based Automatic Test Equipment (KATE) project, LISP code has been written that automatically infers the structure of simple black-box circuits. After testing the circuit via a commercial real-world interface and building a table of corresponding inputs and outputs, KATE builds a knowledge-base to monitor, diagnose and control the circuit, and draws the circuit diagram on a CRT. This is called "learning from observed performance," and has direct application to the automatic creation of knowledge-bases to control and monitor hardware systems.

To date, the system has been demonstrated on simple digital logic circuits and has been partially implemented for analog circuits. Circuit control has been demonstrated through goal-oriented functions that search the knowledge-base for commands that can be changed to produce a desired output. All possible command combinations are presented as options to the operator to meet his goal. This command technique eliminates the need for low-level canned procedures for component control. The KATE project will attempt to develop a complete automatic testing system for black-box devices. John Jamieson at KSC explains that "the objective is to build a complete controller monitor system that's rooted in knowledge-based concepts. The system would be a sort of embryonic HAL from 2001; it talks, tells you what it's going to do and what it does; it detects anomalous measurements, performs a diagnosis, locates broken parts and finally writes its own list of steps to get around the problem so that a system can return to a working operational configuration."

The projects described above are but a few of NASA's current initiatives in expert systems. Future issues of NASA Tech Briefs will provide updates on these projects and explore other NASA activities related to artificial intelligence. □

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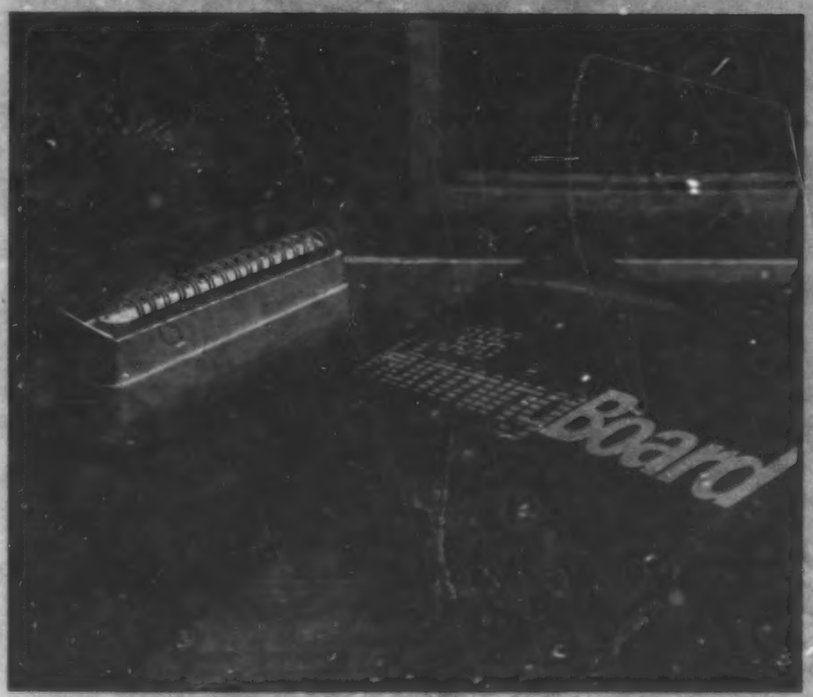

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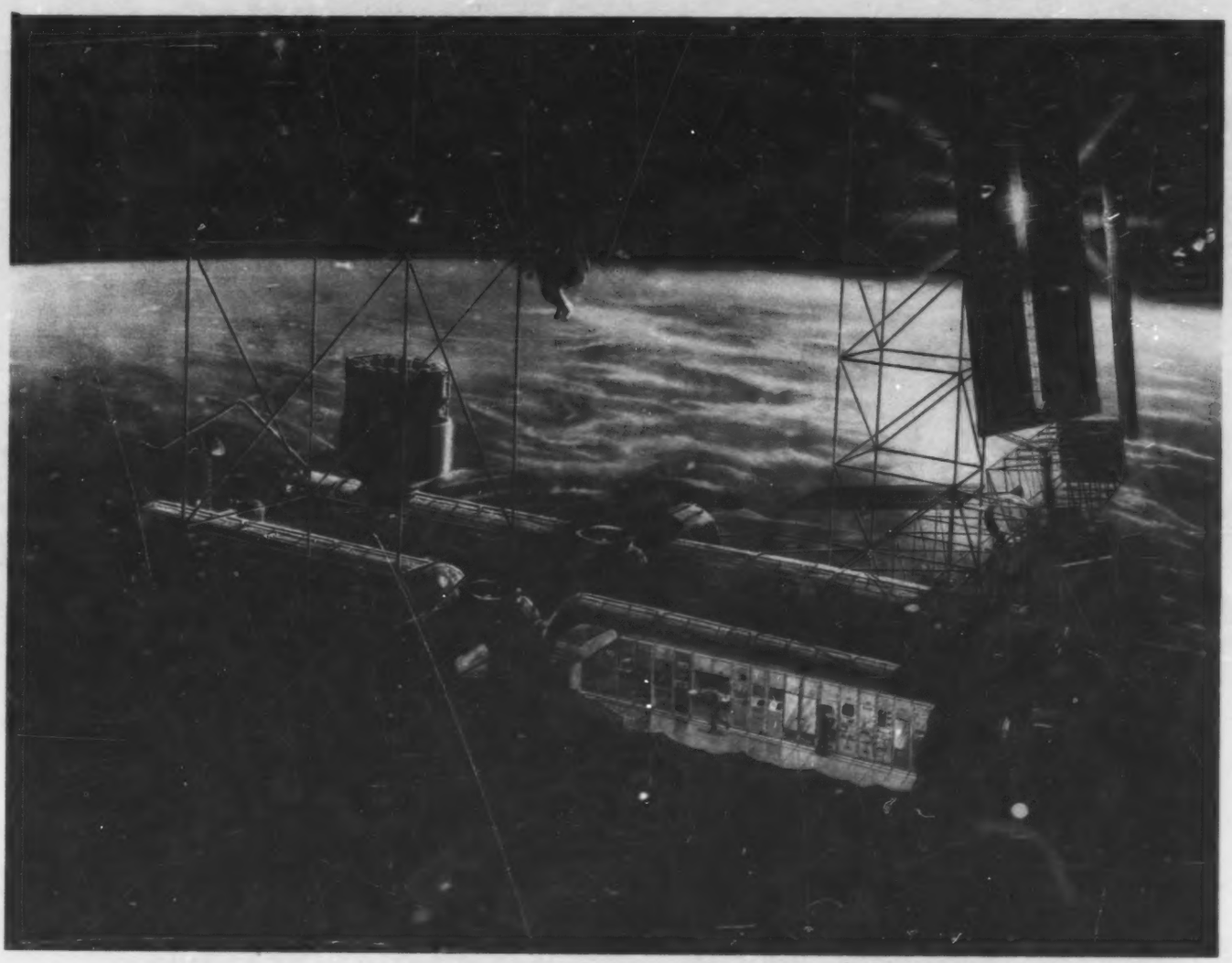

A close-up view of the four pressurized modules that will make up the baseline configuration of the Space Station. The Ada language has been selected for use in all Space Station software.

NASA's Ada Connection

In 1975, the Department of Defense (DoD), seeing the need to consolidate some of the many software languages they were maintaining at that time, sought a multipurpose standard language that could be used for embedded computer systems. A standardized language would bring with it a number of benefits, including that of reducing the costs of designing and implementing compilers and support software, as well as portability.

The "High-Order Language Working Group," garnering worldwide input to the proposed language, devised a series of documents, starting with STRAWMAN and running through STEELMAN, to define the language requirements. The designers took the opportunity to include some of the many advances in programming language technology. Such advances included software development methodology, software management techniques, software modularization and structuring, and software quality.

With an emphasis on reliability and maintainability, the Working Group selected four contractors to produce preliminary designs. These four companies were then pared down to two ►

and given a year to develop their designs. The Cii Honeywell Bull (Louveciennes, France) design was selected by DoD in 1979. It was primarily developed by Dr. Jean Ichbiah, and named Ada.

NASA first became involved with Ada through the Office of Aeronautics and Space Technology, and then through Johnson Space Center, selected in 1983 as one of two federal Beta test sites for DoD's newly-developed compilers.

Ideally suited for the life-cycle of large, complex applications, Ada has been selected for the Space Station. One of Ada's strengths is its support for parallel, fault tolerant program modules–especially important for the Space Station. At the Goddard Space Flight Center (GSFC), several projects are being used to assess Ada's suitability for NASA use and to gain expertise in the language.

GSFC's Mission Operations and Data Systems Directorate

Goddard's Mission Operations and Data Systems Directorate (MO&DSD) is reviewing Ada and its support environments under the guidance of Bob Nelson. Pilot projects are being used to understand Ada's impact on the software development life cycle. These include the Attitude Dynamic Simulator for the Gamma Ray Observatory; the Multi-Satellite Operations Control Center simulator, and the Flight Dynamics Analysis System.

Attitude Dynamic Simulator for Gamma Ray Observatory

Developed concurrently in both Ada and Fortran, the Attitude Dynamic Simulator (ADS) project contrasts the software development process. The ADS models the Gamma Ray Observatory's orientation in its dynamic rotations during torquing and maneuvers. With the software instrumentation process developed by Goddard's Software Engineering Laboratory, several methods are available to measure productivity and the number of changes and errors.

MO&DSD researchers are comparing the Fortran and Ada designs and the time required for their implementation. Says Nelson, "They'll change the specs when the projects are completed to see what happens when the program is modified, how easy modifications are on both the Fortran and the ADA versions. To get an outside perspective, they'll bring in a different person to do those changes."

The ADS project is currently in the implementation phase. In the requirements and the design phases, the Ada domain has taken 10-20% more resources, according to Nelson. He adds, "The key is that the learning cycle is involved; this is a first project."

Other Ada Projects at Goddard

The Flight Dynamics Analysis System project, due for completion in March, 1987, is another way the Goddard team is gaining Ada expertise. The project targets a spacecraft's orbit, determining its orbital location, orientation and velocity. Though the concept changes, the design is kept up to date because Ada's modularity minimizes the extent of any modifications.

The Multi-Satellite Operations Control Center (MSOCC) simulates the functions of a mission control center, processing simulated telemetry from a satellite and sending it commands. A small team for the MSOCC easily generated 10,000 lines of code, and showed high productivity figures in the latter stages of the program's development, according to Nelson. ►

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NASA

In the foreground of this artist's concept of the Space Station is the solar dynamic power system. Solar array panels will also be used to generate electricity for the station. Pressurized modules for the crewmembers are shown in the center of the photo.

Summarizing his Ada results, Nelson mentions "With the large, fully instrumented ADS project, we can show what the characteristics are and validate for project managers who have a very conservative nature. There is a reduced level of risk; there are a lot of benefits to using Ada in the long term. A lot of the benefit of Ada comes when other projects can reuse some of the software."

He adds, "A lot of the experience we're gaining from the smaller projects is helping us make decisions and plan for future Ada uses. One of the things I'm involved in is the Software Support Environment, a definition and development for the Space Station."

Ada and the Space Station

Ada has been selected as the language for the Space Station Software Support Environment (SSE). An extensive software engineering environment such as Space Station includes a large number of tools; software development is much more than just the compiler—it includes requirements analysis, design tools and testing tools. Ada supports these well. According to Nelson, "Because the Space Station is expected to perform over a 20-30 year life cycle, we have to develop and acquire a sophisticated environment to support it." Ted Humphrey, an Aerospace Technologist in the Data Management Section at Johnson Space Center, says that "Development in both ground and on-board software will be written in Ada as long as a compiler is available." "Exceptions to Ada will be allowed, but only when there is previously produced software that can be picked up and used again or for features that Ada doesn't support well," mentions Nelson.

He adds, "We would like to minimize the amount of hardware-peculiar software so we can move to new hardware technology as it evolves. Tests here at Goddard prove Ada's easy portability from one machine to another."

As pilot programs at Goddard increasingly prove Ada's suitability to NASA and other aerospace applications, an intensive Ada instruction program is underway—and with encouraging results. Nelson is optimistic about Ada's future: "Project Managers ask me, as they're in the procurement phase: 'Do you think Ada is ready?' I think it is; we've shown that in the last year and a half through our different pilot projects. So I think we're at the threshold of selecting Ada for other projects." □

COSMIC:

NASA's Software Treasurehouse

Generating thousands of lines of code each year, NASA's programmers toil at their terminals, developing the most basic and most essential aspect of any modern automated system: the programs that enable computers to work.

Recognizing that the fruits of this effort should be disseminated as widely as possible, NASA established the Computer Software and Management Information Center (COSMIC) in 1966 as a contract between the University of Georgia and Marshall Space Flight Center. Its purpose: to distribute NASA-developed software to industry. COSMIC's scope extended NASA-wide in 1967, with the University of Georgia continuing as the operator.

As COSMIC celebrates its 20th anniversary year, its library of available, applicable programs is 1200 strong, with approximately 20 new ones added each month. Potential customers can purchase a catalog, select programs that seem appropriate, and request documentation to make a final determination. Software, purchased separately on either magnetic tape or floppy disk format, includes source code.

NASA-subsidized, COSMIC's state-of-the art programs are available at a fraction of their development cost. Most programs in COSMIC's library cost $1000 or less, with some as low as $25.

Purchasing a COSMIC program isn't a single-event phenomenon; the Center's staff helps clients adapt programs to their own hardware. Should a software bug arise, COSMIC's experts will track it down, or contact the program's author for his input.

NASA programs submitted for the library are reviewed by COSMIC's staff and compiled at the University of Georgia, often on the same type of equipment they were developed on. Documentation is reviewed for completeness, and if the software has application outside of its original purpose, it is added to the library.

Potential COSMIC programs should be submitted to the Technology Utilization Officer (TUO) at the appropriate NASA Center, who will forward them to COSMIC. According to John A. Gibson, COSMIC's Director, "We are looking for generalized programs that have as broad an application base as possible."

NASA employees or contractors interested in COSMIC's programs should contact their TUO. COSMIC's address is given on page 42.

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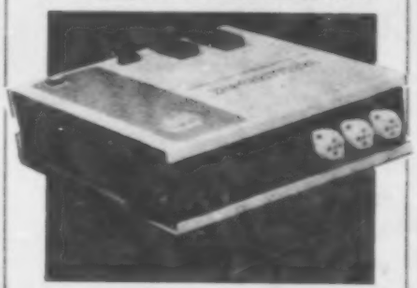

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Golden Oldies

Because software becomes obsolete with time, COSMIC housecleans every two to three years, removing programs that haven't been requested for five years. "Golden Oldies," programs that have kept their relevance over time, are described here:

SPAR—Structural Performance Analysis and Redesign (Engineering Information Systems, Inc.) SPAR is a system of computer programs designed to perform stress, buckling, vibration, and thermal analysis of large linear finite element structural models. LAR-12213; LAR-12370; LAR-12371; LAR-12542; MFS-23944
Circle 1 on the TSP Request Card.

STAGSC-1—Structural Analysis of General Shells (Lockheed Missiles & Space Co.) The STAGSC-1 computer program is intended primarily for the practical engineering analysis of thin shell structures. These shell structures may contain a number of separate shell branches or segments connected to one another along their boundaries. HQN-10960; HQN-10962; HQN-10967
Circle 2 on the TSP Request Card.

PASCO—Structural Panel Analysis and Sizing-Code (NASA Langley Research Center). PASCO was developed for the buckling and vibration analysis and sizing of prismatic structures having an arbitrary cross section. PASCO is primarily intended for analyzing and sizing stiffened panels made of laminated orthotropic materials and is of particular value in analyzing and sizing filamentary composite structures. LAR-13004; LAR-13164
Circle 3 on the TSP Request Card.

PAFAC—Plastic and Failure Analysis of Composites (NASA Langley Research Center). A three-dimensional finite-element computer program called PAFAC has been developed for the elastic-plastic analysis of fiber-reinforced composite materials and structures. LAR-13183
Circle 4 on the TSP Request Card.

FLAGRO4—Advanced Crack Propagation Predictive Analysis (Rockwell International Corp.). FLAGRO4 was developed as an aid in predicting the growth of pre-existing flaws and cracks in structural components. MSC-18718; MSC-18721
Circle 5 on the TSP Request Card.

SINDA—Systems Improved Numerical Differencing Analyzer with Sinflo (TRW Systems Group). SINDA is a software system developed for solving physical problems governed by diffusion-type equations which can be modeled by lumped parameter representation. MSC-13805; MSC-18597; MSC-20891
Circle 6 on the TSP Request Card.

TRASYS II—Thermal Radiation Analysis System (Lyndon B. Johnson Space Center). TRASYS II is a computer software system with generalized capability to solve the radiation related aspects of thermal analysis problems. MSC-20448; MSC-21030
Circle 7 on the TSP Request Card.

General Thermal Analyzer (Rockwell International Corp.). The General Thermal Analyzer program solves transient and steady-state thermal problems using desk-top computers. MSC-20702; MSC-21140
Circle 8 on the TSP Request Card.

LOHARP—Lockheed Orbital Heat Rate Package (Lockheed Missiles & Space Co.). The LOHARP package was developed to calculate the temperature distribution of an orbiting space craft. MFS-23980
Circle 9 on the TSP Request Card.

DISCOS—Dynamic Interaction Simulation of Controls and Structures (NASA Goddard Space Flight Center). The DISCOS program was developed for the dynamic simulation and stability analysis of passive and actively controlled spacecraft. GSC-12422; GSC-12810
Circle 10 on the TSP Request Card.

ORACLS—Optimal Regulator Algorithms for the Control of Linear Systems (NASA Langley Research Center). This control theory design package was developed to aid in the design of controllers and optimal filters for systems which can be modeled by linear, time-in-variant differential and difference equations. GSC-13067; LAR-12313; LAR-12953
Circle 11 on the TSP Request Card.

NBOD2—Program to Derive and Solve Equations of Motion for Coupled N-Body Systems (NASA Goddard Space Flight Center). The NBOD2 computer program was developed to aid in the analysis of spacecraft attitude dynamics. NBOD2 is a very general program that may be applied to a large class of problems involving coupled N-body systems. GSC-12846
Circle 12 on the TSP Request Card.

IAC—Integrated Analysis Capability (NASA Goddard Space Flight Center). The objective of the Integrated Analysis Capability (IAC) systems is to provide a highly effective, interactive analysis tool for the integrated design of large structures. IAC was developed to interface programs from the fields of structures, thermodynamics, controls, and system dynamics with an executive system and a database to yield a highly effecient multi-disciplinary system. GSC-12992; GSC-12994
Circle 13 on the TSP Request Card.

Golden Oldies

SHABERTH—Thermal Performance of a Shaft Bearing System (SKF Industries, Inc.). The computer program SHABERTH was developed to predict the steady state and transient thermal performance of a multi-bearing shaft system operating with either wet or dry friction. LEW-12761
Circle 17 on the TSP Request Card.

QSONIC—Full Potential Transonic, Quasi-Three Dimensional Flow through a Rotating Turbomachinery Blade Row (NASA Lewis Research Center). The QSONIC computer program has been developed for calculating the full potential, transonic quasi-three-dimensional flow through a rotating turbomachinery blade row. LEW-13832
Circle 19 on the TSP Request Card.

PANAIR—Predicting Subsonic or Supersonic Linear Potential Flows about Arbitrary Configurations Using a Higher Order Panel Method (Boeing Computer Services Co.). PANAIR (an abbreviation for "Panel Aerodynamics") is a state-of-the-art system of computer programs developed to predict inviscid subsonic and supersonic flows about an arbitrary configuration by means of a higher order panel method. ARC-11398; ARC-11499
Circle 20 on the TSP Request Card.

INCA—Interactive Controls Analysis (NASA Goddard Space Flight Center). The INCA program was developed to provide a user friendly environment for the design and analysis of linear control systems, primarily feedback control systems. GSC-12998
Circle 14 on the TSP Request Card.

TSONIC—Transonic Velocities on a Blade-to-Blade Stream Surface of a Turbomachine (NASA Lewis Research Center). This program obtains a transonic flow solution on a blade-to-blade surface between blades of a turbomachine. The flow must be essentially subsonic, but there may be locally supersonic flow. LEW-10977
Circle 15 on the TSP Request Card.

MERIDL—Velocities and Streamlines on the Hub-Shroud Midchannel Stream Surface of an Axial, Radial, or Mixed Flow Turbomachine or Annular Duct (NASA Lewis Research Center). This computer program was developed for calculating the subsonic or transonic flow on the hub-shroud mid-channel stream surface of a single blade row of a turbomachine. LEW-12966;
Circle 16 on the TSP Request Card.

Three Dimensional Potential Flow Program with Geometry Package for Generation of Input Data (McDonnell Douglas Corp.). A computer program for calculating viscous effects on the lifts and pressure distributions of arbitrary three-dimensional configurations has been developed by combining a panel method, which calculates potential flow about arbitrary three-dimesional lifting configurations, with a two-dimensional boundary-layer method which is used in a strip-theory sense. LAR-12623
Circle 21 on the TSP Request Card.

GRAPE—Two Dimensional Grids About Airfoils and Other Shapes by the Use of Poisson's Equation (NASA Ames Research Center) The GRAPE computer program was developed to incorporate a method for generating two-dimensional finite-difference grids about airfoils and other shapes by the use of the Poisson differential equation. ARC-11379
Circle 22 on the TSP Request Card.

PROFILE—The Eppler Program for the Design and Analysis of Low-Speed Airfoils (Stuttgart Univ.). The PROFILE computer program was developed as an aid in the design and analysis of low-speed airfoils. LAR-12727
Circle 23 on the TSP Request Card.

NCOREL—Nonconical Relaxation for Three-Dimensional Nonlinear Supersonic Potential Flow (Grumman Aerospace Corp.). The NCOREL program employs a new computational technique for the prediction of inviscid, nonlinear supersonic aerodynamics. LAR-13346
Circle 24 on the TSP Request Card.

Hidden Line Computer Code (NASA Dryden Flight Research Center). The requirement for computer-generated perspective projections of three-dimensional objects by way of line drawings has escalated significantly in recent years. Mathematician David Hedgley of NASA's Dryden Flight Research Facility has developed a new efficient solution to the hidden line problem, and has incorporated it into a Hidden Line Computer Code. ARC-11446
Circle 25 on the TSP Request Card.

SHADE—Shaded Color Picture Generation of Computer Defined Arbitrary Shapes (NASA Ames Research Center) The SHADE computer program was developed to provide for the generation of realistic shaded color pictures from computer defined arbitrary shapes. ARC-11496
Circle 26 on the TSP Request Card.

LONGLIB—A Graphics Library for the Dec Vax Computer (Cal Tech/Jet Propulsion Lab.). This library is a set of subroutines designed for vector plotting to CRT's and dot matrix printers. NPO-16666
Circle 27 on the TSP Request Card.

ELAS—Earth Resources Laboratory Applications Software (NASA Earth Resources Laboratory) ELAS software is a geobased information system designed for analyzing and processing digital imagery data. ERL-10016; ERL-10017; ERL-10018
Circle 28 on the TSP Request Card.

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Computer Programs

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COSMIC: Transferring NASA Software

COSMIC, NASA's Computer Software Management and Information Center, is the one central office established to distribute software that is developed with NASA funding. COSMIC's role as part of NASA's Technology Utilization Network is to ensure that NASA's advanced software technology is made available to industry, other government agencies, and academic institutions.

Because NASA's software development efforts are dynamic and ongoing, new programs and updates to programs are added to COSMIC's inventory on a regular basis. *Tech Briefs* will continue to report information on new programs. In addition, the 1986 edition of the *COSMIC Software Catalog* is available with descriptions and ordering information for available software. Several new programs for control systems/robotics, expert systems, thermal analysis, turbomachinery design, structural analysis, and computer graphics are offered.

For additional information on any programs described in this issue of *Tech Briefs*, circle the appropriate number on the TSP card at the back of the publication. If you don't find a program in this issue that meets your needs, you can call COSMIC directly at (404) 542-3265 and request a review of programs in your area of interest. There is no charge for this information review.

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Computer Programs

These programs may be obtained at a very reasonable cost from COSMIC, a facility sponsored by NASA to provide tested and reliable software to the public. For information on program price, size and availability, circle the reference number on the TSP and COSMIC Request Card in this issue.

Electronic Components & Circuits

Grid-Optimization Program for Photovoltaic Cells

Power loss due to electrical resistance and shadowing is minimized.

The CELLOPT program was developed to assist in designing the grid pattern of current-conducting material on a photovoltaic cell. CELLOPT analyzes the parasitic resistance losses and shadow loss associated with the metallized grid pattern on both round and rectangular solar cells. Although CELLOPT can perform sensitivity studies, it is used primarily to optimize the grid design in terms of the bus bar and grid lines by minimizing the power loss.

The collecting bus bar may be of the same metal and thickness as the grid lines or it may be "strapped", i.e., thicker and of a different material. The bus bar is orthogonal to the grid lines. A round cell may have one or two bus bars, and a rectangular or square cell may have any number.

The power-loss analysis in CELLOPT calculates the contact resistance; shadow loss; and resistances due to the photovoltaic sheet, grid lines, and bus line. The optimization method follows a modified Newton-Raphson procedure. To optimize the grid design the designer may choose any two or all three of the following variables: bus-bar width, grid-line width, and grid-line spacing.

The user must supply such cell electrical parameters as the maximum voltage and current density, the resistivity of the metal and semiconductor sheet materials, and the locations of the bus bars. CELLOPT calculates the minimum total power loss for a given set of characteristics and tabulates such information as the component power losses, volumes, and shadows.

CELLOPT is written in APL for interactive execution and has been implemented on a UNIVAC 1100-series computer. This program was developed in 1985.

This program was written by Ronald E. Daniel and Thomas S. Lee of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 146 on the TSP Request Card.*
NPO-16804

Aerodynamic Prediction for Supersonic Canard-Tail Missiles

Pressure loads and moments are predicted.

The LRCDM2 computer program was developed to calculate the pressure distribution at points on the surfaces of a complete supersonic missile. The missile can comprise up to two finned sections attached to an axisymmetric body of circular cross section. LRCDM2 includes the effects of vortex shedding due to the forebody and forward fins, providing more accurate rolling moments.

LRCDM2 is applicable for mach numbers up to 6 and angles of attack up to 25°. The predicted aerodynamic loads are in good agreement with actual measurements of flow characteristics. Experimental results are described for a rectangular wing, a delta wing, triform tail fins, and a canard-controlled configuration.

The detailed static aerodynamic-loading analysis in LRCDM2 is based on supersonic paneling and line-singularity methods coupled with vortex-tracking theory. Two-dimensional nonlinear Carlson shock-expansion and supersonic-strip theories are combined with three-dimensional linear analysis to modify interference shells on the missile body. The vortex-trajectory calculations incorporate nose-vortex shedding and fin leading- and/or side-edge vorticity characteristics. An optional afterbody vortex-shedding program included in this package can be used alone or in conjunction with LRCDM2 to examine the effects of afterbody vorticity on the tail-fin pressure distribution.

The input to LRCDM2 includes the size and shape of the missile, modeling options, the body orientation, and the flow conditions. The output from the program details the pressure distribution, aerodynamic loads, and moments. It also shows the cumulative effects of fin and body vortexes at control points across the body.

LRCDM2 is written in FORTRAN IV for batch execution and has been implemented on a CDC Cyber 170-series computer operating under NOS with a central-memory requirement of approximately 270K (octal) of 60-bit words. This program was developed in 1985.

This program was written by Marnix F. E. Dillenius of Nielsen Engineering and Research, Inc. for **Langley Research Center.** *For further information Circle 142 on the TSP Request Card.*
LAR-13527

Orbital-Lifetime Program

The long-term effects of small perturbations are predicted.

The Orbital Lifetime Program (OL) analyzes the long-term motion of Earth-orbiting spacecraft at altitudes of up to 2,500 km. It models perturbations to the orbit caused by solar-radiation pressure, atmospheric drag, and gravitational effects of the Sun, the Moon, and the oblate Earth. OL can be used to perdict the orbital lifetime and decay rate of a satellite.

The atmospheric-density models used in OL are the U.S. Standard Atmosphere for altitudes below 90 km and the Jacchia model for altitudes above 90 km. The Jacchia model requires the solar flux and geomagnetic index for the date of the orbit. An input file containing these values for 1984 to 1998 is supplied with the OL package. The solar-radiation-pressure calculations in OL will predict the amount of time a spacecraft is subjected to the Earth's shadow. The input to OL includes space-

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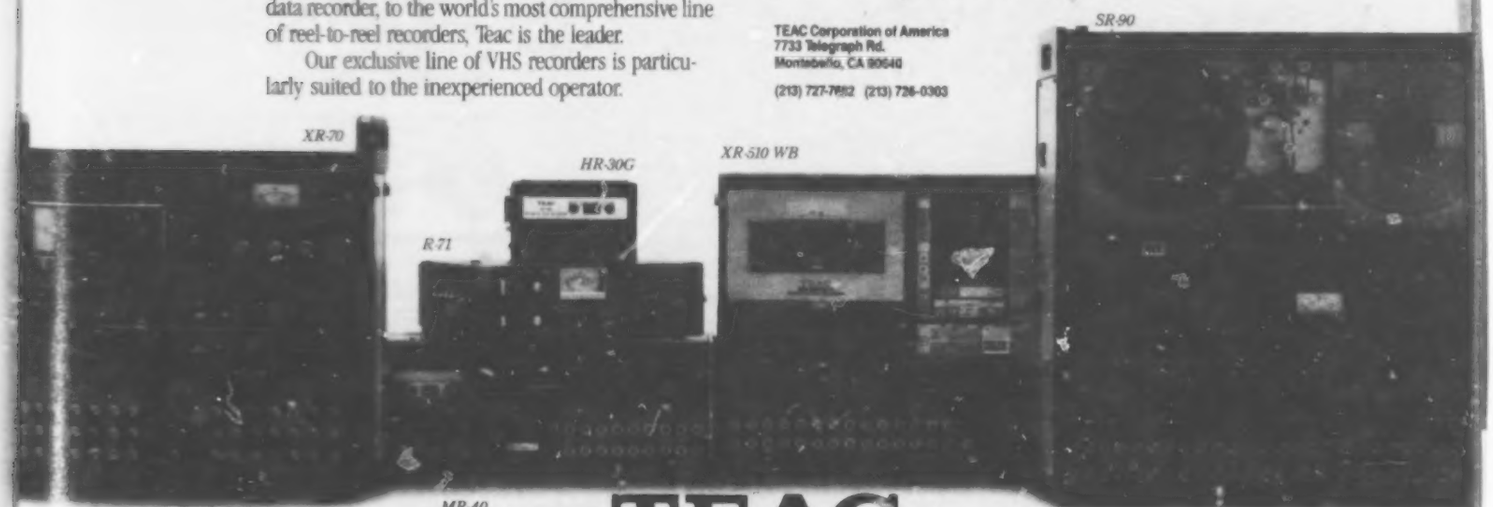

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craft physical characteristics, initial orbit parameters, and the launch date and time. OL calculates time histories of the orbital elements, total lifetimes, and decay rates. A spacecraft is considered "down" at an altitude of 64 km. OL also generates a file of plot data that can be put into a user-supplier graphics program for lifetime plots of altitude against time.

OL is written in FORTRAN 77 for interactive or batch execution and has been implemented on a DEC VAX-series computer operating under VMS. This program was developed in 1985.

This program was written by Lynne H. Orr of **Langley Research Center**. *For further information, Circle 143 on the TSP Request Card.*
LAR-13557

Machinery

Advanced Rotordynamic Nonlinear Transient Simulation

Loads and displacements are predicted for a variety of rotating machinery.

The advanced rotordynamic nonlinear transient-simulation program, TRANSIM, was developed to predict the response of high-performance rotating machinery to a variety of forcing functions. The program works by modal superposition of rotor and casing subsystems (or two simultaneously rotating subsystems). The transient response of the system is calculated by numerical integration of the equations of motion, performed in modal coordinates. The resulting data are transformed back into physical coordinates as required to determine the user-requested loads and accelerations as a function of time. TRANSIM has been used to analyze the Space Shuttle main engine high-pressure fuel turbopump.

TRANSIM allows the user to couple the rotor to the casing with linear and nonlinear interconnecting elements. Linear connectors between the two subsystems can account for forces resulting from intergroup stiffness, damping, and effective inertia, as well as forces from rotating and fixed effective inertia at a specified location. Stiffness, damping, and effective inertia forces can also be applied within (i.e., intragroup) either subsystem.

Nonlinearities in the system are confined to intergroup elements. These elements permit simulations of such rotordynamic phenomena as bearing deadband, tangential rubbing (Coulomb), and piecewise-linear spring rates. Connector parameters can be made dependent on speed. TRANSIM simulates floating-ring seals with Coulomb damping, including the effects of gyroscopic moments in the rotating subsystem.

Forcing functions available for system excitation include rotating unbalance, speed-dependent sideloads between the rotor and casing, and a variable-frequency sinusoidal force applied to the casing. A stability-assessment algorithm determines the logarithmic decrement (or equivalent critical damping ratio) of the most predominant modes via a multifrequency decay-rate analysis.

TRANSIM requires uncoupled linear modal representations of the rotor and casing as inputs. The output from TRANSIM consists of printed and plotted root-mean-square time histories of any linear and nonlinear intergroup elements, relative defections, and casing accelerations, as well as fast Fourier transforms of these responses. Intergroup-element-load time-history and orbit plots for any specified time slice can be made, as well as a complete time-history plot of the displacement of a floating-ring seal. Simplified vector analyses are performed on the intergroup loads to determine fixed and alternating components and fixed load or displacement angles.

TRANSIM is written in FORTRAN 77 for batch execution and has been implemented on a CDC CYBER 800-series computer operating under NOS with a central-memory requirement of approximately 222K (octal) of 60-bit words. This program requires the IMSL and DISSPLA commercial software libraries and is coded to support an SC4020 plotter for graphics output. TRANSIM was developed in 1985.

This program was written by David G. Becht of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information, Circle 107 on the TSP Request Card.*
MFS-19939

Mathematics and Information Sciences

Program for Experimentation With Expert Systems

Deductions are performed according to data and to rules set by the user.

CERBERUS is a forward-chaining, knowledge-based system program useful for experimentation with expert systems. The inference-engine mechanism in CERBERUS performs deductions accord-

ing to a user-supplied rule set. Information is stored in an intermediate area, and the user is interrogated only when no applicable data are found in storage. Each assertion posed by CERBERUS can be answered with a certainty ranging from 0 to 100 percent. The rule processor stops investigating (or "firing") applicable rules when a goal reaches a certainty of 95 percent or higher.

CERBERUS is capable of operating for a wide variety of domains. Sample rule files are included for animal identification, pixel classification in image processing, and rudimentary car repair for the novice mechanic. The user supplies a set of end goals or actions (for example; car needs oil; chemical is sulfur), which are obtained by a combination of assertions (engine runs hot, and water level is high; sample is yellow, burns, and is a nonmetallic solid). The system complexity is decided by the user's rule file, since each assertion may be composed of previous assertions (water level is high when engine is off; choke is wedged open).

The CERBERUS rule file is created by the user with an ordinary text editor in free format. The rule file may contain comments, equations, and rules. A rule consists of assertions (possibly linked by operands), a conclusion clause, and a strength factor. The strength factor is the percentage of the final conclusion to be determined by that particular rule. The initial rule file can be analyzed by CERBERUS to give a breakdown of vocabulary, and tables of assertions, equations, and rules: CERBERUS provides options for tracing the network of rules as the program operates, logging all user replies, and recounting the rules used to reach a given conclusion on an "as-fired" basis.

CERBERUS is written in FORTRAN 77 for interactive execution and has been implemented on a DEC VAX-series computer operating under VMS. The program is general in structure and should be transportable to other systems. CERBERUS was developed in 1985.

This program was written by Steven W. Engle of Informatics General Corp. for **Ames Research Center**. *For further information, Circle 78 on the TSP Request Card. ARC-11688*

Listing Relationships Among Subroutines

Hierarchical charts of subprograms are generated.

The HIERARCHY program is a tool that assists users in obtaining information about the relationships among subroutines in a computer program. HIERARCHY uses the FORTRAN source code and load maps generated by the Cray FORTRAN compiler to generate tables of attributes for each module, including input and output operations, entry points, arguments, and NAMELIST's. These tables also describe the relationships of modules to modules and of modules to COMMON's.

The COMMON's, both labeled and unlabeled, are checked for consistent length. HIERARCHY will note the frequency distribution of calls to other modules and library or service routines. The program generates an optional hierarchical chart of subprograms to show how they relate to the main program. HIERARCHY can accommodate programs of up to 50 calls deep.

HIERARCHY is written in FORTRAN 77 for batch execution and has been implemented on a Cray X-MP computer operating under COS with a central-memory requirement of approximately 133K (octal) words. This program was developed in 1984.

This program was written by Clayton Guest of Informatics General Corp. for **Ames Research Center**. *For further information, Circle 79 on the TSP Request Card. ARC-11609*

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A Case of Bidirectional Technology Transfer

By James E. Tomayko

One of the prime benefits of the space program is the transfer of technology to such areas as materials science, medicine, and electronics. This often has been a one-way street. However, one NASA research program not only resulted in adapting space flight techniques to the realm of aeronautics, but also to using an advanced form of the aeronautical technique to prove a concept incorporated in the Space Shuttle. This double technology transfer was accomplished during the Digital Fly-by-Wire Program conducted at the Dryden Flight Research Center in Edwards, California, during 1970-1978. Phase One used Apollo hardware to establish fly-by-wire technology, and Phase II acted in part as a testbed for Space Shuttle software.

The Concept of Digital Fly-by-Wire

Digital fly-by-wire is a method of controlling an aircraft electronically rather than mechanically. From the Wright brothers until recently, the dominant way to move an airplane's control surfaces (elevators, ailerons, rudder, flaps) has been with mechanical linkages from the cockpit control devices. For example, a pilot pulling back on his control stick moves a cable or rod attached to the base of the stick and connected to the elevators, usually through a hydraulic system that enhances the force of the pilot's pull, enabling him to easily move the control surface. In a digital system, the mechanical path to the control surface is broken. Devices are inserted to convert stick and rudder pedal manipulations to voltages. These voltages are measured and the data are entered into a set of control laws programmed into a digital computer. The computer outputs the appropriate commands to actuators that then control the force applied through the hydraulic system. With a sufficiently sophisticated set of control laws, the airplane can be made more "flyable."

The concept of digital control was applied in the manned space program. The only method of controlling the Mercury, Gemini, and Apollo manned spacecraft was by the use of rockets, both small thrusters for attitude control and minor orbit changes and large engines for major corrections to the flight path. The Mercury capsules had neither a digital computer nor an orbital maneuvering system, just attitude control jets that could be fired either by the astronaut or the ground controllers. The Gemini spacecraft contained a computer used as a back-up for the launch-vehicle guidance computer and for rendevous and reentry operations. Gemini had some lifting capability and could be maneuvered during descent within a "footprint" some 400 miles long and a few dozen miles wide by controlling its attitude.

However, it was the Apollo program that most extensively used fly-by-wire techniques. The Apollo missions included a considerable amount of automatic attitude control, and that was accomplished using the computer to fire thrusters. The computer also calculated and conducted main engine burns for course corrections, orbit changes, and the like. The ►

Fly-by-wire techniques of the future are simulated in the Ames Proximity Operations (Prox-Ops) Space Station mockup as an operator transfers an Orbiting Maneuverable Vehicle (OMV) to the Space Shuttle. Pioneering fly-by-wire technology originated with the Space Shuttle, shown here on its Boeing 747 carrier plane, and its partner, the Digital Fly-by-Wire F-8C.

astronauts could control the spacecraft only through this digital system.

Origins of the Digital Fly-by-Wire Program

As the Apollo program scored its greatest successes in late 1968 and 1969, a group of engineers at NASA's Dryden Flight Research Center considered the use of digital control techniques for aircraft. There appeared to be obvious advantages to testing such a system, as digital fly-by-wire promised to revolutionize the design of high-performance aircraft such as the F-16 and the current X-29 with forward-swept wings. One advantage for such aircraft is in more precise maneuver control, another is increased combat survivability due to the presence of redundant systems. Large commercial aircraft could benefit because better control would mean a smoother ride for passengers and cargo. Also, weight and space savings could result. But before such systems were applied to either military or commercial flight, they had to have proven reliability. The success of the manned space program indicated that digital systems could be made reliable, but their use in controlling aircraft remained a problem to be solved.

The key consideration in a digital system is the type and capabilities of the computer to be used in it. Due to reliability considerations, the Flight Research Center engineers wanted to have a redundant set of computers. However, the cost of developing and man-rating a new computer for this program was high. Therefore, the already-existing Apollo guidance computer with its inertial measurement unit and related devices became the digital system for the program. There was a disadvantage to using the Apollo system; it was developed exclusively for use on the Apollo spacecraft, with no thought of other applications. This meant that some significant adaptations needed to be made before it could work in an aircraft. Several advantages outweighed this consideration:

—The Apollo computer was so carefully constructed, with such attention to piece-part screening and testing, that it could be used confidently as a simplex system, with no redundancy, just as in the Apollo spacecraft.

—Several Apollo missions were cancelled, making surplus (and already paid for!) equipment available.

—The project could press on immediately, due to existing Apollo contracts with Delco (digital hardware), the Charles Stark Draper Laboratory of the Massachusetts Institute of Technology (software), and Sperry (analog back-up devices).

—Software development and support facilities were in place. Software, as learned during the Apollo experience, is often the pacing item in a project involving computers. The existence of tools to assist in software development was an important factor in the program's rapid implementation and success.

Thus equipped, the conversion process began for what the Dryden engineers claim was the world's first aircraft with "full authority" digital fly-by-wire.

From Mechanical to Digital: The Metamorphosis of an Airplane

The airplane chosen for fly-by-wire demonstrations was the Vought F-8 Crusader. NASA acquired several of these aircraft for research purposes. One of NASA's F-8s became the test aircraft for supercritical wing research. Two others were assigned to the fly-by-wire program. Dryden engineers removed the portions of the wing of an F-8A that folded for carrier storage and modified it further into a test-bed. Permanently grounded, this "Iron Bird" made possible the testing of the hardware and software associated with the program before clearing it for flight. A pilot could sit in the Iron Bird simulator and move control surfaces driven by equipment identical to the flight version.

One advantage is more precise maneuver control.

The first step in transforming the aircraft to a digital-controlled vehicle was breaking the chain of mechanical linkages. To provide electrical inputs to the computer, linear variable differential transformers (LVDTs) were installed to convert the mechanical stick and rudder pedal movements. Engineers installed LVDTs for pitch on the right side of the aircraft aft of the cockpit. Roll LVDTs were put on the left side of the airplane. Due to rudder cable stretching, the yaw transformers were at the base of the tail. When the pilot moved the stick or rudder, the portion of the mechanical cable that remained between the control device and its LDVT also moved, affecting the voltage output from the transducer. The voltages were input to an interface unit that converted them to a format understandable by the software.

The next part of the conversion process was installing the surplus Apollo hardware. The Apollo guidance computer was a fixed-point machine using 16-bit words that had a cycle time of 11.7 microseconds, slower than most personal computers today. It came with 36k words of mixed memory and 2k words of erasable memory.

The Apollo spacecraft flew with two computers, one in the command module and one in the lunar excursion module. Their hardware was identical, but the software was necessarily different. The astronauts communicated with the computer through a display and keyboard unit (DSKY) which contained a keyboard for entering numbers and commands, and five-digit displays for data as well as warning lights.

The F-8 carried a DSKY in the left gun bay, where a ground crewman could activate the flight control program before takeoff. The DSKY was a crude data entry and retrieval system, even for the 1960s, compared to the simplest home computer of the 1980s, but Dryden engineers considered it "pretty good compared to what we had later" in Phase II. This was because the DSKY allowed specific parameters stored in the erasable memory to be changed between flights. The Phase II software came from Draper on tape, with no interface capable of changing it.

The software structure was quite similar to that used in Apollo. The programs were divided into systems and applications programs. Systems programs included the Executive, which essentially controlled the running of the other programs; Restart, which provided a graceful means of beginning the program cycle again after a hardware or software failure; and Service, which did some internal testing and other tasks. Flight control was the primary purpose of the applications programs. Draper took the system software directly from a load prepared for the Apollo 14 flight, making it possible for the developers to concentrate on the applications programs.

Changing the actuator's function in the hydraulic system was another modification to the F-8. Signals from the computer would travel through the interface unit and then to the actuators. Each control surface has secondary electro-hydraulic actuators driving a metering valve in the primary hydraulic power actuator. The secondary actuators have redundant servo valves. In the Phase I program, three valves were present to move each hydraulic system. One was prime, and ►

did the actual work; the other two were back-up. In Phase II, all servos drive the hydraulics together.

This set of components, the LVDTs, computer and initial measurement unit (IMU), software, interface unit, and actuators, complete the transition from a mechanical control system to a digital fly-by-wire system. However, a back-up system had to be provided. To prove the feasibility of fly-by-wire beyond question, the aircraft could not carry a mechanical control system of any sort. Because the electrical equipment was already in the design, an analog electronic back-up using a triply-redundant system was installed. Faults detected in the primary control system caused a switchover to the backup. Examples of such faults are a parity failure in the computer, software entering into an endless loop, an attempt to read data in a part of memory that contained no data, and others detectable by the primary system's hardware or software. A restart or complete switchover would occur depending on the fault's severity or repetition. In all Phase I and Phase II flights, no automatic switchovers ever occurred. The engineers tested the back-ups by having the pilot manually change over to the analog system during several flights.

The Phase I Flight Program

Preparation for the Phase I Flight Program began with testing the digital equipment and its software on the ground. Those tests demonstrated some ways in which the concepts of the control laws needed changes before flight. For example, in early hardware tests, engineers used a hand controller from the lunar module in place of a stick. This was only a matter of convenience, even though it was known that the stick would be used later. This masked a problem that showed up in the Iron Bird when a real stick was used. The difficulty was "coarse quantization" of the inputs by the computer when the stick was moved. The minumum step size for signals created by the software caused commands to the actuators in response to pilot movements to be sent in too-short increments. When this happened, the entire simulator would shake violently, with a frightening noise level.

Despite the racket, the anomaly probably would not be catastrophic in flight, although the pilot would feel the aircraft maneuver in a very coarse stair-step fashion. A software filter was added to the programming to smooth out the actuator movements. This suggested two things to future digital control efforts: a high-fidelity simulator with actual hardware and software is of critical importance in verifying the total system, and software can often overcome hardware deficiencies or idiosyncrasies.

When the actual flight tests finally took place, they were almost anticlimactic. In 42 flights totaling 58 hours, the digital system operated without a failure or restart. Pilots could choose to fly the F-8 in either "direct" or "stability augmentation system" (SAS) modes. The latter provided feedback to automatically reduce the piloting task. Test pilots could even fly direct in one or two axes, and SAS in the remaining axes. This part of the program paved the way for using digital systems to improve pilot performance in difficult-to-fly aircraft or spacecraft of the future.

Transition to Phase II: Testbed for the Space Shuttle

While the F-8 made aviation history at Dryden, NASA prepared for its next manned spacecraft program—the Space Shuttle. The concept of a reusable spacecraft dictated that the ►

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vehicle should have the ability to control its movement through the atmosphere to a much greater extent than was possible in any previous manned program. To manuever during the glide portion of each Shuttle mission, the craft needed a control system for its moveable surfaces. Having separate control systems for space and the atmosphere would be unnecessary duplication. Therefore, a single digital fly-by-wire system would function in both space and during descent. The system became a fully integrated avionics system with a core of five general purpose computers involved in all spacecraft activities from launch processing to powered flight, on-orbit operations and reentry, glide, and landing. Not only would there be no mechanical backup to this system, but no analog backup as well. This meant that the reliability of the primary system had to be extremely high, and that redundancy had to be established within it. In 1973, a three-computer configuration was chosen for the F-8 Phase II hardware. A fourth computer was selected for backup. At the time, a similar hardware scheme was being considered for the Shuttle, so a triplex system on the F-8 would give the Shuttle program a convenient vehicle on which to test both synchronization and redundancy management techniques.

Contributions to the Shuttle Program

The Phase II of the digital fly-by-wire program contributed to the Shuttle in several ways, at least one unplanned. The planned ways included computer synchronization, redundancy management, and the demonstration of data bus concepts that reduced the hardwiring necessary in the control system. The need for redundancy in both the F-8 and Shuttle was due to the fact that each used a mass-produced, off-the-shelf general purpose computer, the IBM AP-101. Because the Shuttle would not have a back-up other than another computer of the same type, it was important that the avionics be able to function if one or more of the primary computers failed. Therefore, graceful reconfiguration of the primary system in flight depended on identifying whether a computer has failed and identifying the failure of any other mission-critical component (such as an actuator) so that its back-up could be engaged.

One way to determine whether a computer has failed is synchronization. Because only one computer is needed to perform all the functions of controlling the F-8 or the Shuttle, the same program can run independently in each of the computers in the system. By starting the computers simultaneously, each computer in the set should be at the same place in the software at the same time, with leeway for minute differences in hardware. In both the F-8 and the Shuttle, discrete signals are sent to each of the other computers at predetermined intervals. When the software is interrupted to check for synchronization, each computer sends a discrete signal to the others. The computers wait for the incoming signals, reset the count on the discretes when both arrive, do a second read to check if the other computers did their resets properly, and then reset the interrupt clock timing the interval between synchronizations. If the signal from another computer does not arrive within a specified time interval, or is incorrect, the waiting computers send a message declaring the delinquent computer "bad" and go about the business of flying the airplane. The failed computer can try a restart, declare itself bad, or keep on, but the other computers ignore it until it properly synchronizes. A failure of two computers causes an automatic switchover to the back-up control system. This entire process is done in less than 10 milliseconds, so short a time that the performance of the aircraft is not affected. The Shuttle system uses four computers in a redundant set instead of three, three discretes instead of two, waits 4 milliseconds instead of 10, and stops on software cues rather than a count, but the concept remains the same as the method used on the F-8.

The failed computer can try a restart, declare itself bad, or keep on, but the other computers ignore it until it properly synchronizes.

Redundancy management is another area in which the F-8 program directly contributed to the Shuttle. Many subsystems on both the F-8 and the Shuttle are triplicated, not only the computers. Signals from each of the three versions of the subsystem must be analyzed for error. The algorithm for evaluation consists of simple rules: if no failures, take the middle value of the three signals; if one failure, average the signals. Because the processes in the AP-101 could be scheduled, two periods of redundancy management were built into each software cycle. One period is used to make the signal selection, the next for fault detection; thus, failed channels are identified before the succeeding cycle begins.

An unplanned area in which the F-8 program contributed to the Shuttle was in the evaluation of pilot-induced oscillations that appeared on the fifth approach and landing test (ALT) flown by the shuttle *Enterprise*. After the problem with pilot-induced oscillations appeared, a series of test-flights of the F-8 was scheduled to try to replicate the problem and experiment with solutions. These tests provided needed data to develop a solution.

Proof of how the Phase II program helped the Shuttle was that out of the four computer failures in the first 50 flights, none caused a switchover to the back-up system, and none caused any noticeable degradation in the handling characteristics of the aircraft. Therefore, the purpose and efficacy of a multiple-string digital system was proved.

Wider Applications of the Technology

The F-8 and Shuttle are contributing to the development of a new flight technology, the Control Configured Vehicle (CCV), which incorporates digital fly-by-wire. The F-16 uses active control by an analog system and is being converted to digital fly-by-wire in the F-16/D models. The Navy's F/A-18 fighter also uses a digital fly-by-wire system. In the United Kingdom, a *Jaguar* fighter is part of a project to test a quadruplex digital system, and data bus concepts are being incorporated on new commercial aircraft as well as military planes. An aircraft that directly benefited from the digital fly-by-wire project is the X-29 with forward-sweeping wings. First flown in December 1984, the plane uses Honeywell computers with the same basic control laws and redundancy management scheme developed in the digital fly-by-wire program. All of these projects have proceeded with confidence because in the early 1970s an F-8 borrowed some space-age technology and repaid the loan with interest.

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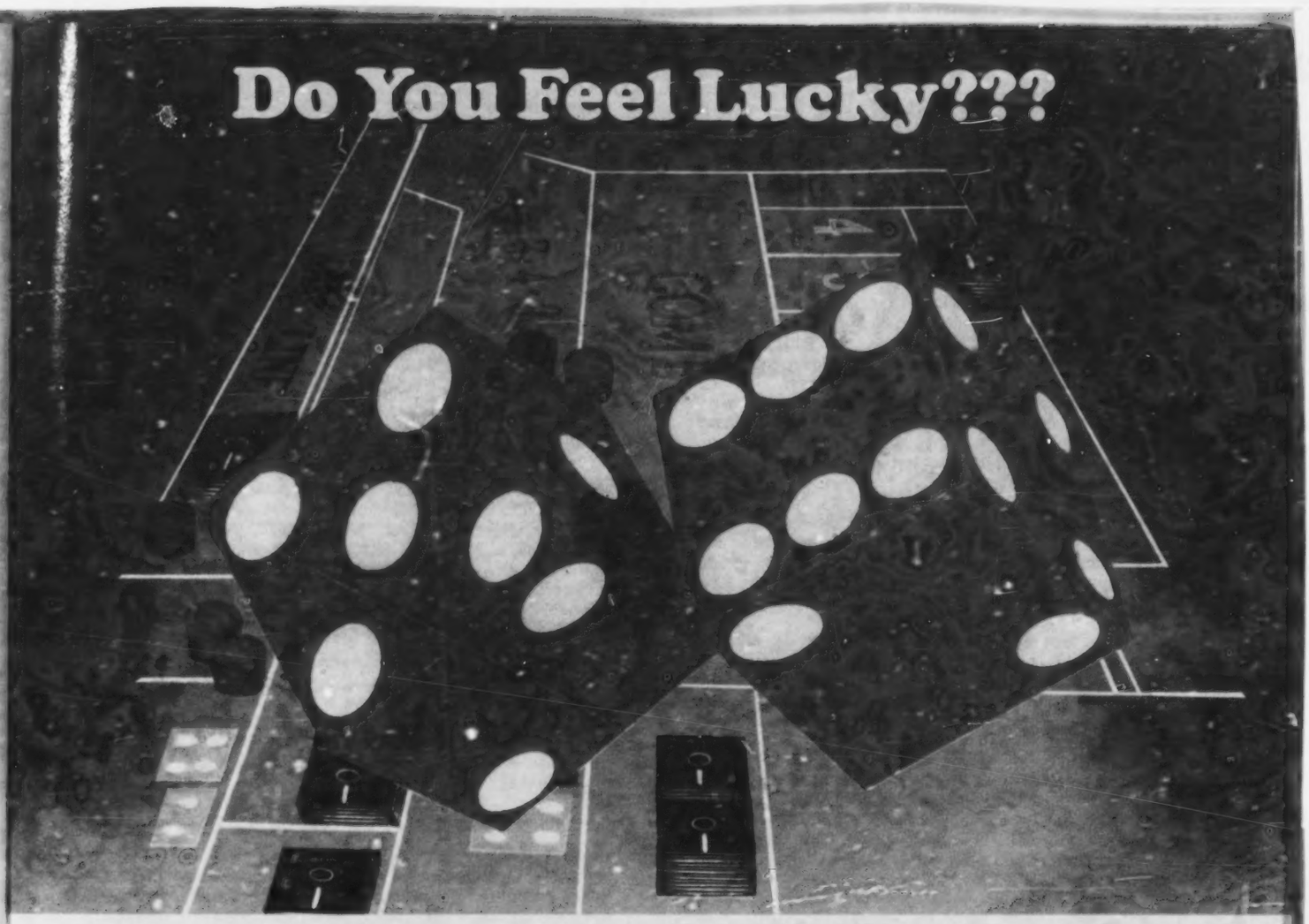

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Suppliers Forecast

Guildline Instruments, Inc., Orlando, FL, has developed a digital platinum resistance thermometer with a temperature range of -200 C to +600 C. The 9540 B has an IEEE 488 GP-IB interface for systems or laboratory application.
Circle Reader Action No. 329.

Flexible Computer Corp., Dallas, TX, offers the FLEX/32 Multi Computer, with parallel processing designed for real time systems. The FLEX/32 supports ADA, C, and FORTRAN languages and has UNIX System 5 capabilities.
Circle Reader Action No. 326.

Systems Control Technology's (Palo Alto, CA) Model C software facilitates modeling, analysis and control of dynamic systems. Block diagrams are drawn with a mouse.
Circle Reader Action No. 327.

Microcompatibles, Silver Spring, MD, adds the IBM-compatible Printmatic FORTRAN-callable printer driver to their graphics software line. Printmatic allows users to access the full capabilities of a dot-matrix or laser printer.
Circle Reader Action No. 328.

Honeywell's Tabular Monitoring software package pretests monitoring options for transducer activity review. The package includes online data and derived (real-time) channel monitoring, and alarm condition recognition. The software can be installed on Honeywell's H.TMS 3000 Test Management Systems. **Circle Reader Action No. 301.**

KineticSystems Corporation has a new CAMAC serial highway system for long distance ultra-high-speed data acquisition and time-critical process control. KineticSystem's distributed I/O format allows data transfer within a single Serial Highway message, providing transfer rates five times greater than other real-time highway systems.
Circle Reader Action No. 333.

TRAQ Technology Inc., of Baton Rouge, LA, introduces TRAQ-NET, a "smart" data collection system that processes data for dBase III files. TRAQ-NET links up to 999 data capture devices in a multi-sharing network. Information gathered through the terminal and software can be communicated to a PC host immediately or stored at the work station for communication to the host at a more convenient time.
Circle Reader Service No. 330.

Inference Co., of Los Angeles, CA, offers expert systems technology for a new line of computer Integrated Manufacturing (CIM) products under development by **American Cimflex Corp.** inference's new products can be used for plant-floor control and information management at the automation workcell and machine levels.
Circle Reader Action No. 331.

MARC Analysis Research Corporation, Palo Alto, CA, produces nonlinear finite element analysis software that simulates the effects of heat and stress on products and manufacturing equipment. MARC's companion graphics interface program, a pre-and post-processor called MENTAT, generates models enabling users to 'see' the results of an analysis. The MARC/MENTAT combination runs on a wide variety of computers, including the leading engineering workstations. **Circle Reader Action No. 323.**

Applicon, a Schlumberger company, introduces their 68020-based Bravo3 Manufacturing Workstation, a 32-bit UNIX system with a 19-inch high-resolution monochrome graphics screen. A mass-storage subsystem enables operation as a stand-alone unit or as part of an Ethernet-TCP/IP network. Included is the COMPACT II Numerical Control programming language, a 2-D graphics system for blueprint creation and other mechanical and process documentation.
Circle Reader Action No. 308.

Aptec's recently introduced I/O Computer, the IOC System 200, a special-purpose input/output computer, accelerates the throughput of I/O-intensive applications on DEC's VAX/VMS minicomputers in excess of 50 times. In a typical application, the IOC efficiently supports up to a dozen high-performance peripherals and devices. It provides a 200 Mbytes/sec internal bus, programmable 12 Mbytes/sec I/O processors and high-speed mass memory with access rates up to 50 Mbytes/sec per memory board. **Circle Reader Action No. 310.**

Gold Hill's new 386 LISP System includes the HummingBoard, a 386-based plug-in board with up to 24 Mbytes of directly addressable on-board memory for IBM PC XTs and ATs, and the Golden Common Lisp (GCLISP) 386 Developer. The HummingBoard serves as a co-processor capable of executing GCLISP programs five times faster than an IBM AT. The GCLISP 386 Developer is a Common LISP programming environment used for development and delivery of AI applications. **Circle Reader Action No. 311.**

Nicolet Test Instruments (formerly Nicolet Paratronics) announces four new dedicated probes for its 800 series logic analyzers, which support the 68008, 68010, and NSC800 microprocessors, and the IEEE-488 bus. The probes easily connect to the test unit, and disassemble collected data into microprocessor or GPIB mnemonics. All models include high impedance buffering, qualifiers to purge unwanted bus cycles, and disassembly software. **Circle Reader Action No. 313.**

R.R. Software, combining microcomputing and military/industrial contracting, offers products and services for microcomputer-based Ada. Janus/Ada, a compiler line for 16-bit systems, and PasTran, an ANSI STD Pascal to ANSI STD Ada translator, were released in 1982. The company also sells other Ada related products, including an Ada tutorial, an embedded systems development package, and Ada application programs ranging from an editor to complete graphics capabilities. **Circle Reader Action No. 314.**

Control Data Corporation announces two 1750A computers for the space and avionics markets. The computers will be based on Control Data's two-chip CPU running over 2 MIPS using the standard DAIS floating point instruction mix. The CPU has received U.S. Air Force certification. Full form-fit and function engineering units will be available in the second half of 1987. **Circle Reader Action No. 306.**

Data Precision's new 640 Module and High Speed Sampling Probe, with the DATA 6000 mainframe, can make high speed, high precision measurements to 100 GHz equivalent time sample rates with 16 bit resolution in the 1 GHz bandwidth. The probe can measure fast rise and settling times by digitizing data points 10 psec apart.
Circle Reader Action No. 307.

Digital Equipment Corporation and Systems Designers signed a development agreement to share their Ada technologies and build a family of cross-compilers based on Digital's VAX Ada programming language. The cross-compilers will support the MIL-STD-1750A, Motorola 68000 and Intel iAPX86.
Circle Reader Action No. 324.

MASSCOMP's (Westford, MA) **Scientific Laboratory System (SLS),** a data acquisition computer system designed for laboratory applications, features RTUTM UNIX, for high performance, real-time scientific experiments. SLS includes Laboratory Workbench; mouse-driven software that eliminates programming through pull-down menus, pop-up displays, graphical icons and interactive controls.
Reader Action No. 318.

Visionics Corporation's (Sunnyvale, CA) EE Designer II CAE/CAD integrated software package supports surface-mount design and multilayer layout. The software has the ability to create ground planes on either side of PC boards. User-definable features include trace width and pad sizes, pin-snap, block delete, macro save and multi-step pan. Fabrication drawings can be created with related text through the software's text editor and automatic board-dimensioning capabilities. **Circle Reader Action No. 302.**

Defense Advanced Research Projects Agency (DARPA) awarded **Brimrose Corporation of America** a Phase II research grant to develop a Real-Time X-ray topography system for quality control evaluations of epitaxial films of gallium arsenide (GaAs), gallium aluminum arsenide (GaAlAs) and mercury cadmium telluride (HgCdTe) on various substrates in production environments. Potential applications include evaluating single crystal or large polycrystal substrates and epitaxial film materials. **Circle Reader Action No. 312.**

Boeing Technology Services' (Seattle, WA) Flight Systems Laboratory (FSL) has developed the new direct technical support for programs or contractors, and can serve as an advisor, consultant or auditor. FSL also provides the New Simulation System (NSS), uses parallel processing architecture to develop more realistic flight simulators.
Circle Reader Action No. 319.

Fluoramics, Inc., Upper Saddle River, NJ manufactures Compu-Lube, a lubricant marketed for use on fine mechanisms on computers. Also new is Tufoil, an oil additive that lowers mechanical friction. Tufoil's chemistry includes suspended PTFE, or Teflon microparticles, giving it a friction coefficient of 0.02 on the National Bureau of Standards' steel-on-steel 4-ball test. **Circle Reader Action No. 320.**

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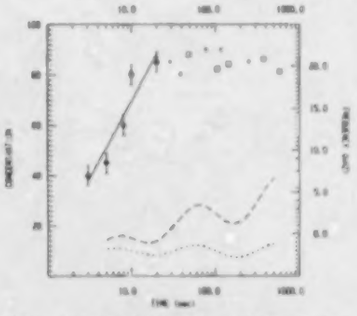

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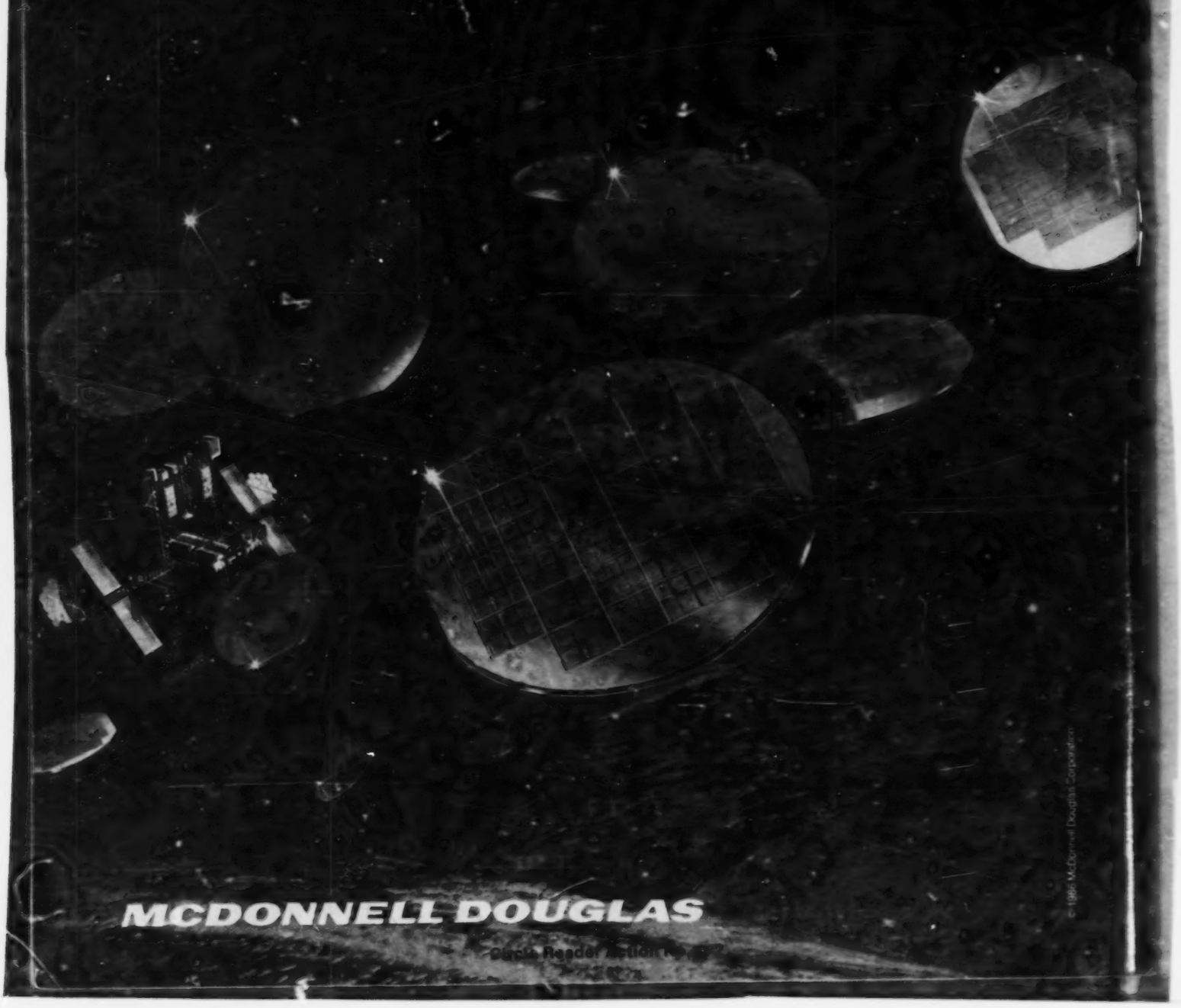

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